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TEST OF THE FEASIBILITY AND ACCURACY OF MASS AND VELOCITY MEASUREMENTS ON PELLETS IN FLIGHT IN A MICROWAVE SET-UP WITH A PASS-HOLE IN THE TRANSMISSION LINE

V. Andersen and P. Andersen

Abstract. The feasibility of mass and velocity measurements on pellets in flight without use of optical equipment has been tested. The mass is measured by a microwave system, and the velocity is measured by a time of flight in a double interaction with the microwave system. The influence of the size of the pass-holes in the microwave guide tube has been discussed.

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1. INTRODUCTION

1.1. General

Injection of frozen pellets of deuterium or other hydrogen isotopes may be necessary in large tokamaks for refuelling, control of density profile, diagnostic purposes, etc.. In any case it is important to be able to measure the size and velocity of a pellet without exerting any influence on it. This has been done previously in a system with a combination of optical and microwave equipment[1]. In attempting to simplify the set-up by avoiding the optical part of the system, investigations have been made to test the feasibility of a double interaction with the microwave system. By suitably bending the microwave transmission line, it is possible to allow the pellet to pass the microwave system not only in the measuring cavity at the end of the transmission line for mass measurement, but also directly in the transmission line itself in order to have another timing signal for velocity measurement. A sketch showing the idea of the new set-up is given in Appendix A, Figure 1.

1.2. Applications

With a successful result of these preliminary investigations, the idea is to use this kind of set-up at the ORNL five-shot injector installed at JET. This injector may deliver pellets of equal diameter and length of 2.6 - 6.0 mm. The large pellets and the distance required between the barrel and the measuring cavity combined with the scattering angle of 0.5 degrees for this injector, will give the necessary size of the pass-hole in the cavity and in the transmission line. Figure 1a shows the maximum deviation of the centre of mass of the pellet from the axis of the pass-holes at the position

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1)V. Andersen et al., Equipment for measuring pellet masses and velocities, Operators manual, May 1985, Risø-M-2596.

of the measuring cavity and at the pass-hole in the transmission line, respectively. Nevertheless, it is desirable to keep the dimensions of the waveguide as small as possible because of space demands. The smallest waveguide with a dimension above the largest diameter of the pass-hole is WG 16 (10 x 23 mm internal), and the investigations have been performed with this type of waveguide.

2. SPECIFICATIONS

The system should be used for deuterium pellets at three different sizes: 2.6, 4.0 and 6.0 mm. In the test we have not ben using deuterium pellets, but dummy ones made of teflon. In a system optimized for real deuterium pellets, teflon dummy pellets equal in size to the deuterium pellets would have saturated the measuring system. Therefore, the size of teflon pellets have been chosen as linearly 70% of the real pellets in order to give the same signal as the corresponding deuterium pellets to secure linearity of the sensitivity.

As the signal from the microwave system is proportional to an integration of the electric field over the volume of the pellet, fluctuations in the field will be smoothed out by larger pellets. This will decrease the relative variation in the pellet signal versus the position in the pass-hole for larger pellets. This is clearly seen by comparing the results for different sizes of pellets in the same microwave set-up (see for instance Graph 2, Graph 3 and Graph 4 in Appendix B). For the same reason the variation in signal will be decreased for real deuterium pellets as compared to the dummy pellets. The exact improvement depends on the size of the pass-hole, the size of the pellet and the distortion of the electric field in the region of measurement. Assuming that the electric field is sinusoidal the improvement may be calculated, and gives for the largest hole size in the cavity (13.7 mm) a factor of 1.2 - 1.6 depending of the size of the pellet. It is seen from the measured results that the field is strongly distorted because of the pass-hole as compared to the original sinusoidal shape, especially in the longitudinal direction. However, as a rule of thumb, the variation in pellet signal versus position in the pass-hole may be expected to be decreased because of this size effect with a factor of 1.5 for the real deuterium pellets as compared to the results given in the graphs. Furthermore, the variations from the center to the outer position will be decreased for larger pellets, because the allowed deviation of the center of mass for these pellets are smaller. The improvement by this effect is significant, and may be found from the actual graphs in Appendix B.

As the detection of the pellet is a DC measurement, no effort has been made to shoot the pellets through the pass-hole, which would then introduce an uncertainty in positioning the pellet properly in flight. Instead the pellet has been placed stationary within the microwave cavity, fixed by a 0.03 mm nylon wire with no measurable effect on the microwave signal. With this method the position of the pellet in the microwave can be determined with a relative accuracy of about 0.1 mm, and the response of the pass-holes versus the position of the pellet has been investigated along the axes shown in Appendix A, Figure 2. The influence on the cavity signal of the hole in the transmission line is not critical with respect to the length of the transmission line, and we have used a length of about 1 m.

3. TEST RESULTS

3.1. Cavity response without pass-hole in the transmission line

The distance between the gun barrel and the measuring cavity is expected to be 350 mm. Taking the scattering angle of 0.5 degrees and the size of the pellets into consideration, the holes needed will be:

Cavity hole	Pellet size (deuterium)
13.7 mm	6.0 mm
10.9 mm	4.0 mm
8.9 mm	2.6 mm

It would be convenient if the largest hole were usable for all three sizes of pellets, because the pellet could then be changed without any modification of the measuring cavity. Therefore, the response of the cavity versus the position of the pellet in the pass-hole has been investigated for the following combinations:

Cavity hole	Pellet size (deuterium)
13.7 mm	2.6, 4.0 and 6.0 mm
10.9 mm	2.6 and 4.0 mm
8.9 mm	2.6 mm

The results are given in Appendix B, Graphs 1 - 9.

In all the graphs in Appendix B, we have indicated the size of the pass-hole, and by a hatch area the size of the pellet. Several diaphrams between the transmission line and the cavity have been tested to find a coupling that gives the most constant signal at all positions of the pellet along the longitudinal and transversal axis. The sensitivity has been given by the response in the middle of the hole and the relative a deviations at the two ends of the axis. As the maximum deviation from the axis of the pass-hole to the centre of mass of the pellet, because of the scattering angle of 0.5 degrees, is about 3 mm in the measuring cavity, the average sensitivity inside this radius has been given in the graphs as well. Furthermore, a curve has been given for the response of the cavity along the line of flight of the pellet penetrating the cavity. In Graph 1 the response is given for a plain hole of 13.7 mm in the cavity. With such a large opening, the response was very much influenced by the surroundings of the cavity. To avoid this influence a chimney-pot has been mounted on the hole as shown in Appendix A,

Figure 3. In figure 4 a photograph is showing a cavity with a plain hole as well as a cavity with a chimney-pot. Furthermore, the tuning piston and the diaphram between the cavity and the transmission line are shown. As an extra effect of the chimney-pot it is seen from Graphs 1 and 2 that the response from the cavity is increased by nearly 70%. Graphs 3 and 4 give corresponding results for the middle-size and small pellets. It is clearly seen, as stated earlier, that the local strength of the field is smooted out by the larger pellets. Furthermore, the deviations given for the outer positions of the axes are larger for the smaller pellets, because the centre of mass of these pellets may pass further from the axis of the pass-holes.

In Graphs 5 - 8 the cavity hole has been reduced to 10.9 mm corresponding to the necessary size for the middle-size pellet. Again the response has been investigated with and without chimney-pot, but at this size of hole, the effect in sensitivity is seen to be more marginal (5 - 10%). Furthermore, the influence from the surroundings on a plain hole of this size is not very significant. Therefore, at the smallest size of hole, 8.9 mm (Graph 9), a chimney-pot has not been used.

Some of the graphs for the longitudinal sensitivity show a still increasing or decreasing shape, indicating that the pass-hole is not places in the optimum position. If the deviation at the edge of the hole is within a few percent, the result has been accepted to avoid unnessary and time-consuming efforts, because in such a case, the feasibility and a reasonable accuracy has been demonstrated.

The percentage diviations given in the graphs occur purely because of changes in the sensitivity along the axis, and do not indicate the presence of noise. The noise level is less than 0.4 mV for all the measurements, giving a signal-to-noise ratio of 225 - 8850 for the region of signals observed in the cavity.

As expected from previous experience, good results were obtained for the system without pass-hole in the transmission line if the size of the hole in the cavity corresponds to the size of the pellet. For the large pass-hole used for all three sizes of pellets, the response in the middle of the cavity versus the pellet size has been given in Graph 10, showing a reasonable system linearity.

The fluctuation in the signal along the longitudinal direction is below 10% for the smallest pellet, and even better for the other ones (see Graphs 2 - 4). In the transverse direction the fluctuations are somewhat worse, because the signal must decrease when we approach the side walls of the waveguide. However, taking into consideration that the pellet will be photographed, this could be done in a direction giving the transverse position. This will give the possibility of correcting for this position, and therefore the response of the cavity for all positions of the pellet could easily be within 10% even for the smallest pellet. For this reason, the large size of pass-hole in the cavity has been chosen for the next point: Cavity response with pass-hole in the transmission line.

3.2. Cavity response with pass-hole in the transmission line

The influence on the sensitivity of the cavity because of a hole in the transmission line has been investigated. As a bending of the transmission line with reasonable curvature has no significant influence on the behaviour of the system, we have used a straight system with a distance of about 550 mm from the hole in the cavity to the hole in the transmission line. The sensitivity of the cavity has been investigated for the following combinations of pellets and hole sizes in the transmission line. The size of the hole in the cavity is fixed at 13.7 mm.

Hole size in the transmission line	Pellet size (deuterium)
19.8 mm	2.6 mm, 4.0 mm and 6.0 mm
17.0 mm	2.6 mm and 4.0 mm
15.0 mm	2.6 mm

By comparing Graphs 2 - 4 and Graphs 11 - 13 it is seen, as shown in the table below, that the sensitivity of the cavity has been decreased by a factor of about 2, because of the hole in the transmission line.

Pellet size	Without hole in transmission line	With hole of 19.8 mm in transmission line	Factor	Average
6.0 mm	3540 mV	1780 mV	1.99	
4.0 mm	1140 mV	510 mV	2.24	2.1
2.6 mm	330 mV	160 mV	2.06	

However, the diaphram between the transmission line and the cavity had to be changed because of the hole in the transmission line to obtain reasonable working conditions. Therefore, the hole is not the only difference between the two set-ups. So, the given results indicate that a loss of no more than a factor of two is possible, and this result may even be slightly improved. The tendency that a larger pellet will smooth out the change in electric field, giving a smaller relative variation along the axes seems no longer to be valid. this might be because of the mutual influence between the two holes that alters the field distribution that is affected by a pellet. However, the overall tendency of the relative variations are very much the same as without the hole in the transmission line. This means that in the longitudinal direction a measurement of better that 10% may be expected, whereas for the transverse direction another indication of the position is still needed, in order to correct in the measured signal.

Similar to the situation without pass-hole in the transmission line, the average sensitivity inside a radius of 3 mm has been given in graphs 11 - 12. In attempting to make a scaling to larger geometries, the sensitivity inside a radius of 2 mm and 1.5 mm, respectively, has been given as well. The results of this scaling have been discussed later on.

It is seen from the next graphs. (Graph 12 - 16) that the size of the holes in the transmission line has only minor influence on the sensitivity of the cavity. In the case of a 19.8 mm hole in the transmission line, the linearity of the cavity signal has been tested again as shown in Graph 10. It is seen that the linearity is still completely satisfactory.

3.3. Response of the pass-hole in the transmission line

Along with the investigations of the sensitivity of the cavity for different sizes of hole in the transmission line, the sensitivity of the latter has been investigated as well. Because of the extreme large holes, the deviations along the axes are rather severe, up to a decrease in signal of about 80% as compared to the signal in the middle of the hole. However, these signals are to be used only for a timing signal to give the velocity of the pellet. The size of the signal is therefore unimportant as long as it is sufficient as a trigger pulse. With the smallest pellet placed at the edge of the largest hole, we still found a signal of 20 mV, giving a signal-to-noise ration of 50, which should be sufficient. Comparison with the next graphs (Graph 18 - 22) shows that the size of the pass-hole has only minor influence on the signal in the middle of the hole.

4. DISCUSSION

To evaluate the ability of a microwave system to doubly interact with the pellet, to give as well the mass as the velocity of the pellet, it is necessary to specify the needs in the measurements.

The accuracy in the velocity is only a question of the distance between the two holes, and will depend on the disposed space and the aiming accuracy of the pellet injector. The size of the signal from the pellet in the pass-hole in the transmission line is strongly dependent on the position in the hole. But as this signal is used only as a time trigger this is of no importance.

If an accuracy on the pellet mass of 10% is sufficient, it has been shown that the system is able to fulfil this requirement along the longitudinal axis of the hole, because the hole distorts the field in a suitable way, for this purpose. Along the transverse axis a similar distorsion is not possible because of the close vicinity of the side walls of the microwave tube. Therefore another indication of the pellet position in this direction is necessary to correct the signal. This indication might come from a photograph of the pellet. With such a correction it should be possible to measure the mass within 10% in all cases.

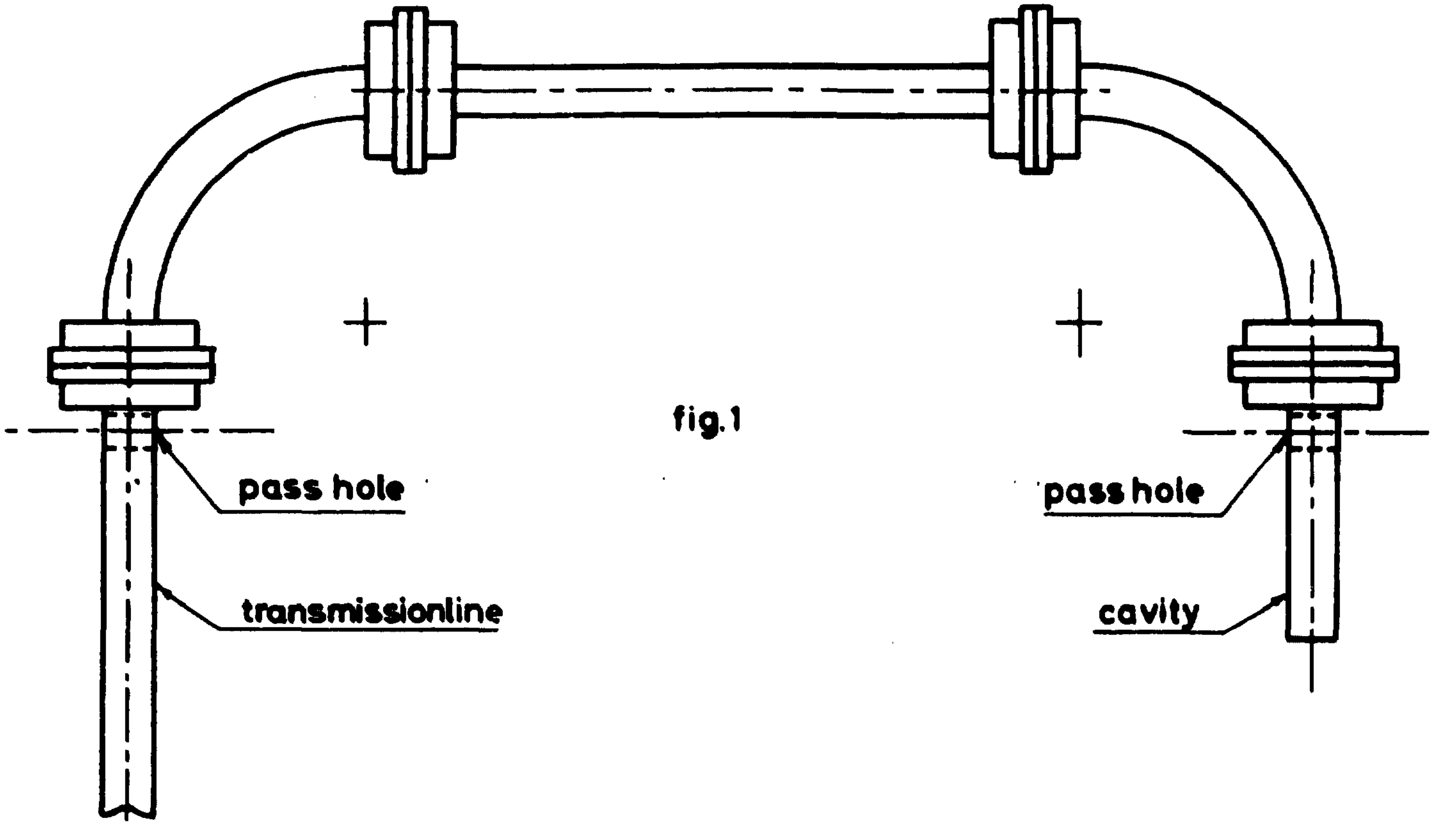
Mounting the system in a real set-up will give problems because the axes of the two holes has to be on exactly the same line, as shown in Appendix A, Figure 1. The strong distorsion of the field pattern due to the holes, will complicate calculating the right position of the holes in the waveguide exactly. So, the right position, giving a symmetrical distribution of the signal along the axis, has been found by an iterative procedure moving the holes as well as the tuning piston in the cavity to the positions for attaining the best result. figure 5 in Appendix A shows the technique in obtaining a movable hole.

An important question about the feasibility of the system is the influence of a long transmission line that will be necessary if the system should be used at JET. The aim of this work has been to investigate the influence of a hole in the transmission line on the sensitivity of the cavity, as well as the sensitivity of the hole itself. For this we have used a 0.9 m long transmission line. We have previously experienced that the cavity system may be used with a long transmission line without serious problems (up to 20 m), but we may expect problems with the sensitivity of the hole in the transmission line. When using this hole for a measurement, the transmission line itself may be seen as a cavity. Normally the signal from a cavity is proportional to the size of the pellet, and inversely proportional to the size of the cavity. In that case the sensitivity of the transmission line should be expected to decrease in proportion to the length of the transmission line. To get an indication of the influence of a long transmission line, we have made a set-up with a length of 7 m. By extrapolating from this system to 20 m indicates that for such a system the signal in the cavity will be decreased by a factor of about 3 and the signal in the transmission line may be decreased by a factor of about 70 as compared to the 0.9 m system (see Appendix C).

To improve the signal from the transmission line, we suggest a new set-up in which the pass-hole in the transmission line is replaced by a side-branch ending in a cavity. We have tried to set-up a system following this principle. This system is shown in Figure 6 in Appendix A. In a real set-up the end of the transmission line will have to be bend to place the pass-holes at the same axis. Without going into detail in investigating this system, we have got the indication that at longer systems, the signal in the side-branch will decrease only with about the same factor as that in the original cavity.

In case a better accuracy is needed, one could possibly go to a larger system to decrease the relative distance from the axis of the pass-hole to the position of the pellet. Decreasing this distance with a factor of two would correspond to a linear increase of the waveguide with the same factor. Therefore, the uncertainty inside a radius of 1.5 mm in WG 16 waveguide system used, would correspond to the uncertainty inside a radius of 3 mm in a WG 12 waveguide system. Similarly, an estimate of a WG 14 system could be found from the uncertainty inside a radius of 2 mm in the WG 16 system. To get a more proper scaling, the size of the pellet ought to be diminished. Furthermore, the size of the pass-hole might be diminished. The first effect will worsen the uncertainty and the latter will improve it. As these effects are expected to be of the same order they cancels out, and the results of the uncertainties inside the smaller areas are taken directly as a rough estimate of the expected results for 3 mm holes in larger waveguide systems. With these reservations Graph 23 shows the expected improvement in uncertainties, obtained by using larger microwave systems.

APPENDIX A



<u>Fig. 1.</u> Sketch showing the idea of the set-up with double interaction of the microwave system. The pellet is coming from the right-hand side allowing the pass-hole in the cavity to be the smallest.

fig. 1a

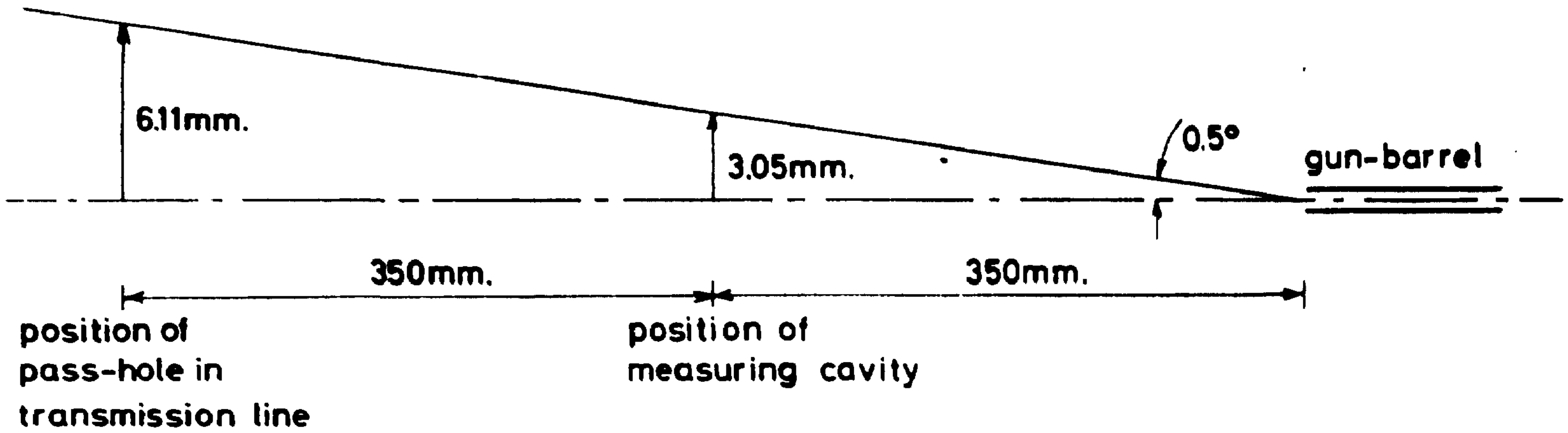
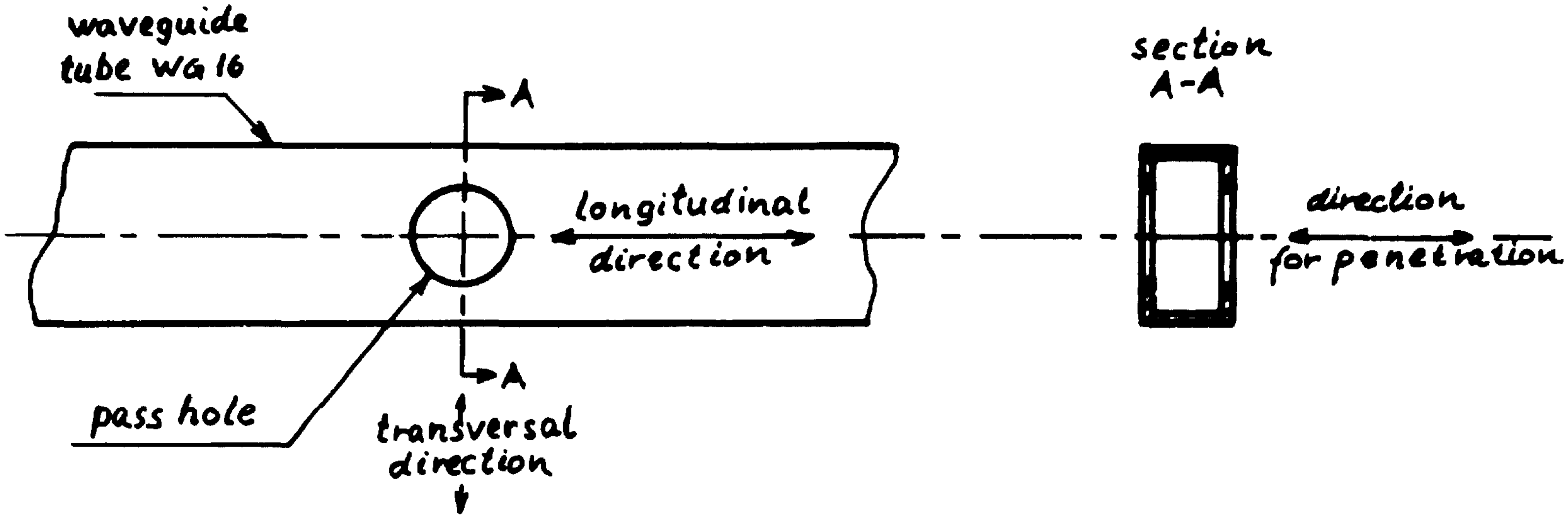
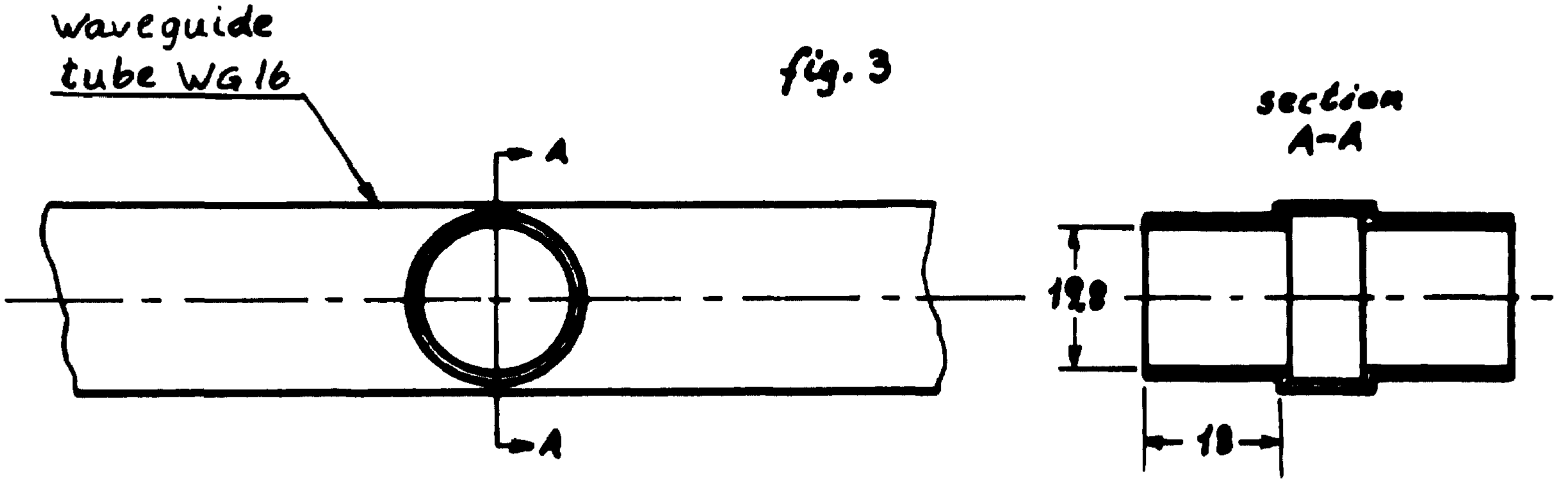


Fig. 1a. Sketch of the maximum deviation of the centre of mass of the pellet from the axis of the pass-holes, because of the scattering angle of 0.5 degrees.



<u>Fig. 2.</u> Indications of the axes along which the sensitivities have been investigated.



<u>Fig. 3.</u> Sketch showing the chimney-pot to decrease the influence of the surroundings.

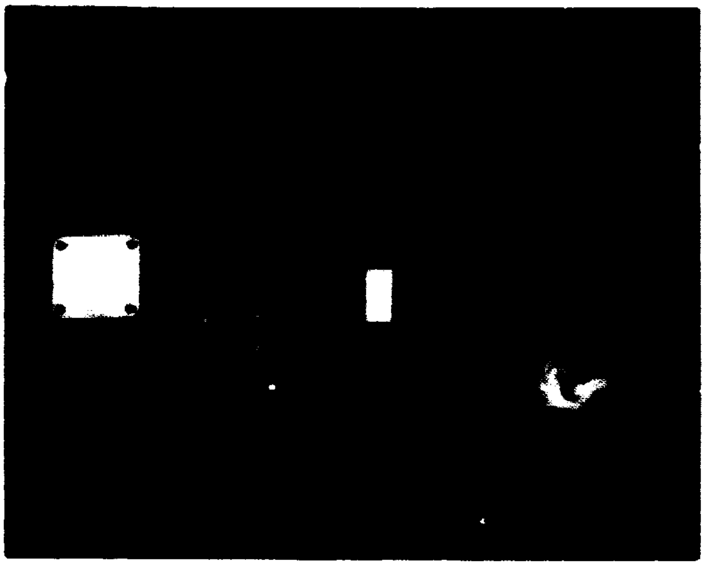


Fig. 4. Photograph of a cavity with a plain hole, and with a hole mounted a chimney-pot, respectively. Furhtermore, a tuning piston and a diagram are shown.

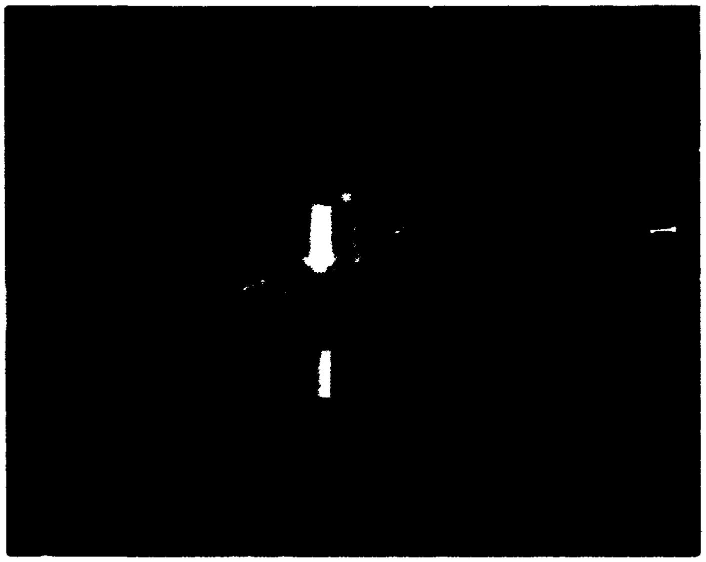


Fig. 5. Photograph showing the technique in obtaining a movable hole in the transmission line.

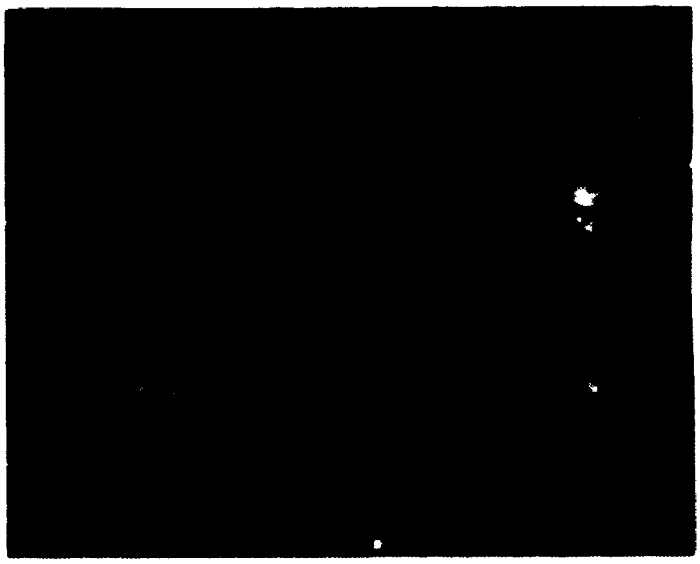
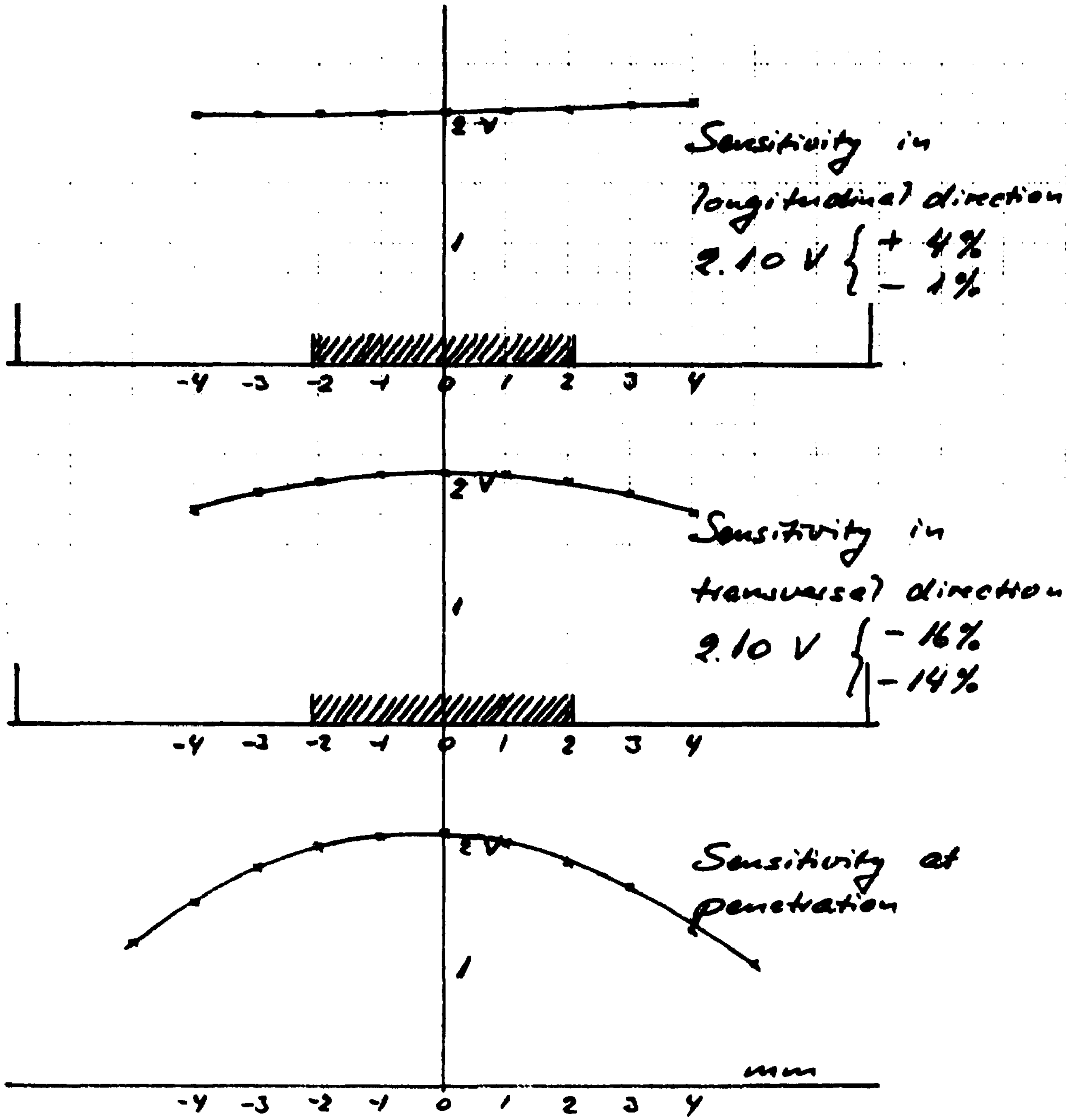


Fig. 6. Photograph showing a test set-up with the hole in the transmission line replaced by a side-branch ending in a cavity.

APPENDIX B

Graph 1

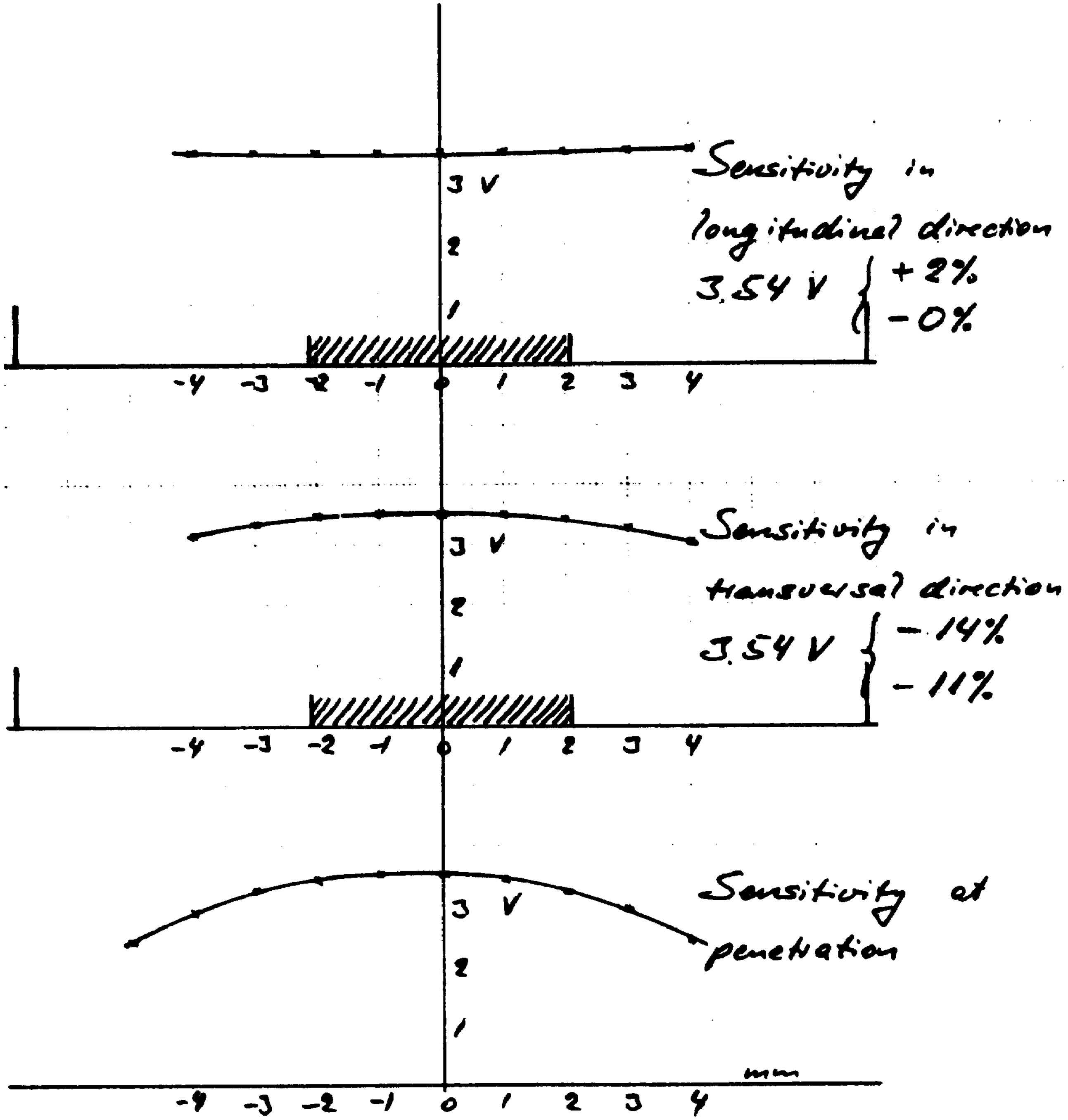


Cavity hole: 13.7 mm
Pellet size:
4.2 mm Teflon
corresponding to
6.0 mm deuterium

Without chimneypot

Average sensitivity for the
centre of mass of the pellet
inside a radius of 3 mm
2.05 V ± 6.1 %

Graph 2



Cavity hole: 13.7 mm
Pellet size:
4.2 mm Teflon
corresponding to
6.0 mm deuterium

With chimneypot

Average sensitivity for the centre of mass of the pellet inside a radius of 3 mm
3.44 V ± 4.2%

Graph 3

Cavity hole: 13.7 mm

Pellet size:

9.8 mm Teflon

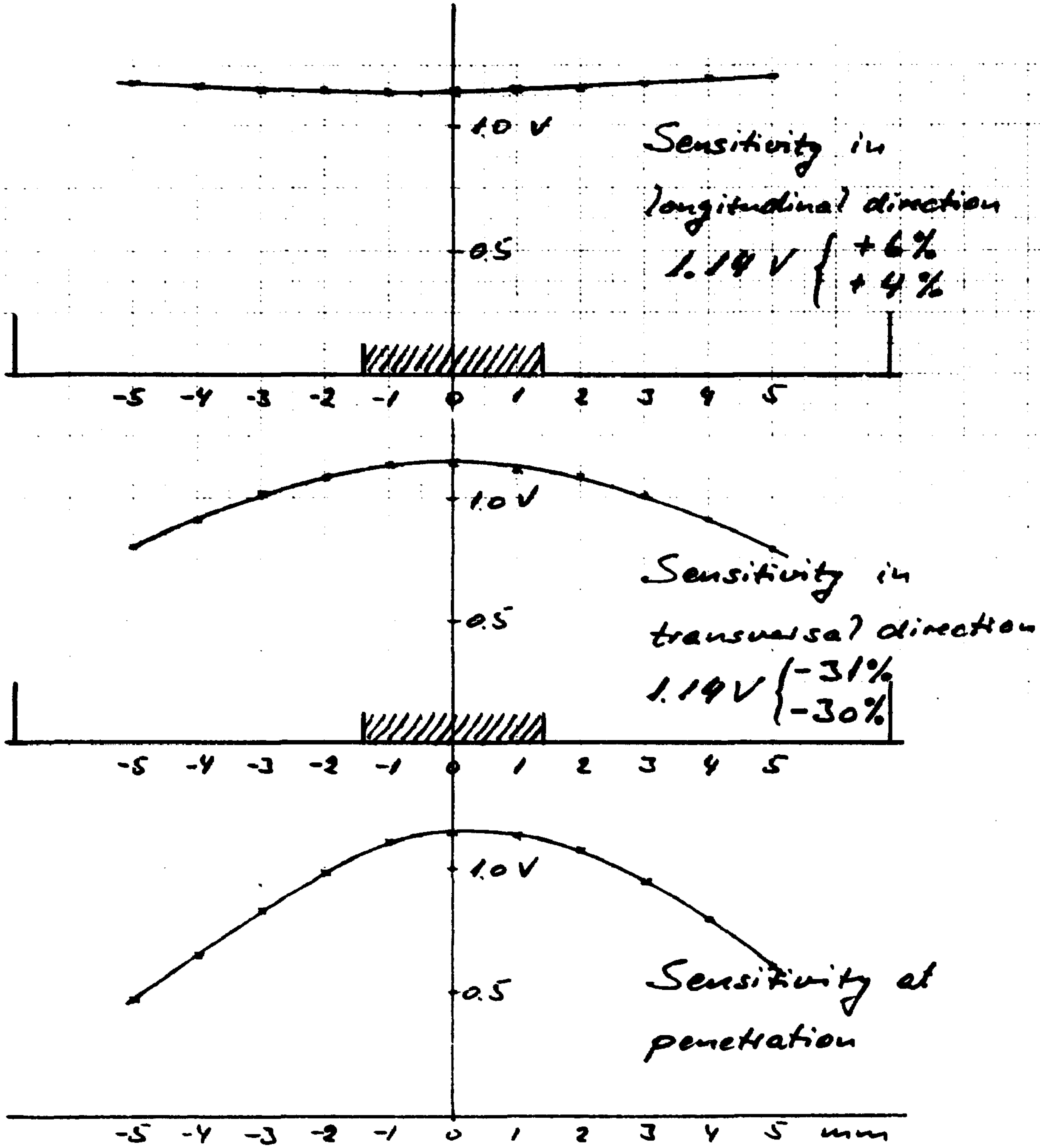
corresponding to

4.0 mm deuterium

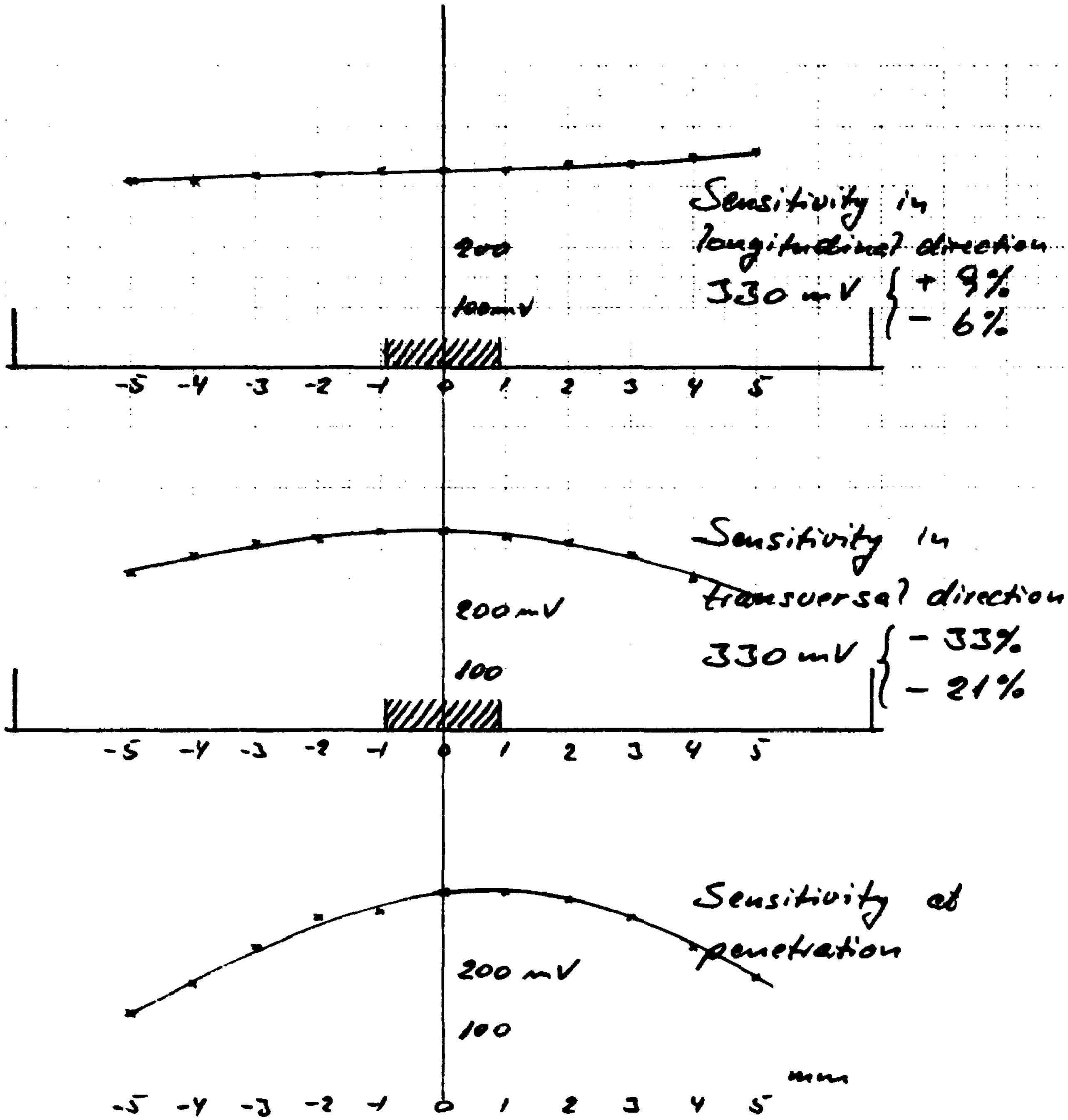
with chimneypot

Average sensitivity for the centre of mass of the pelld inside a radius of 3 mm

1.10 V ± 7.8%



Graph 4

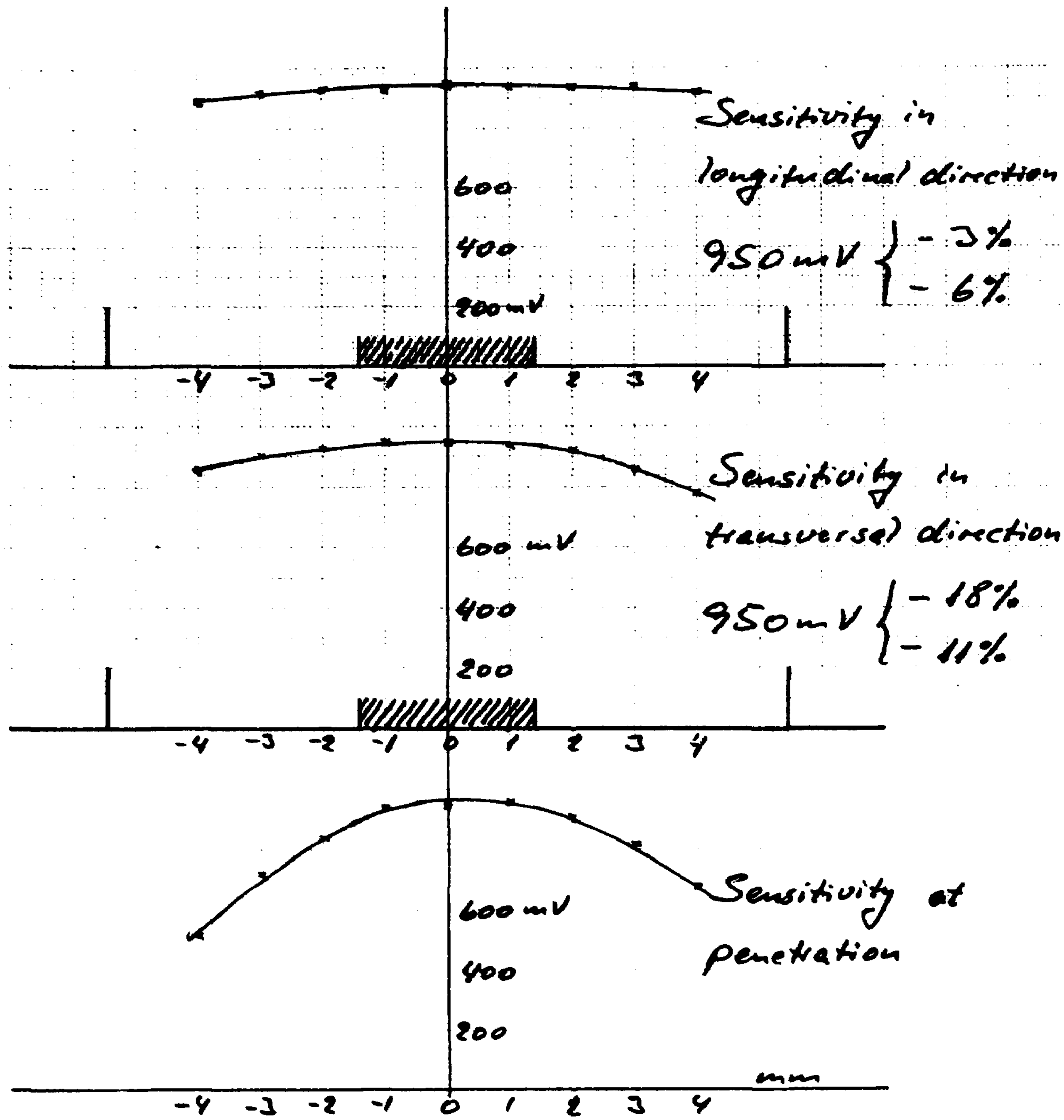


Cavity hole : 13.7 mm
Pellet size :
1.8 mm Teflon
corresponding to
9.6 mm deuterium

With chimneypot

Average sensitivity for the
centre of mass of the pellet
inside a radius of 3 mm
315 mV ± 7.9%

Graph 5

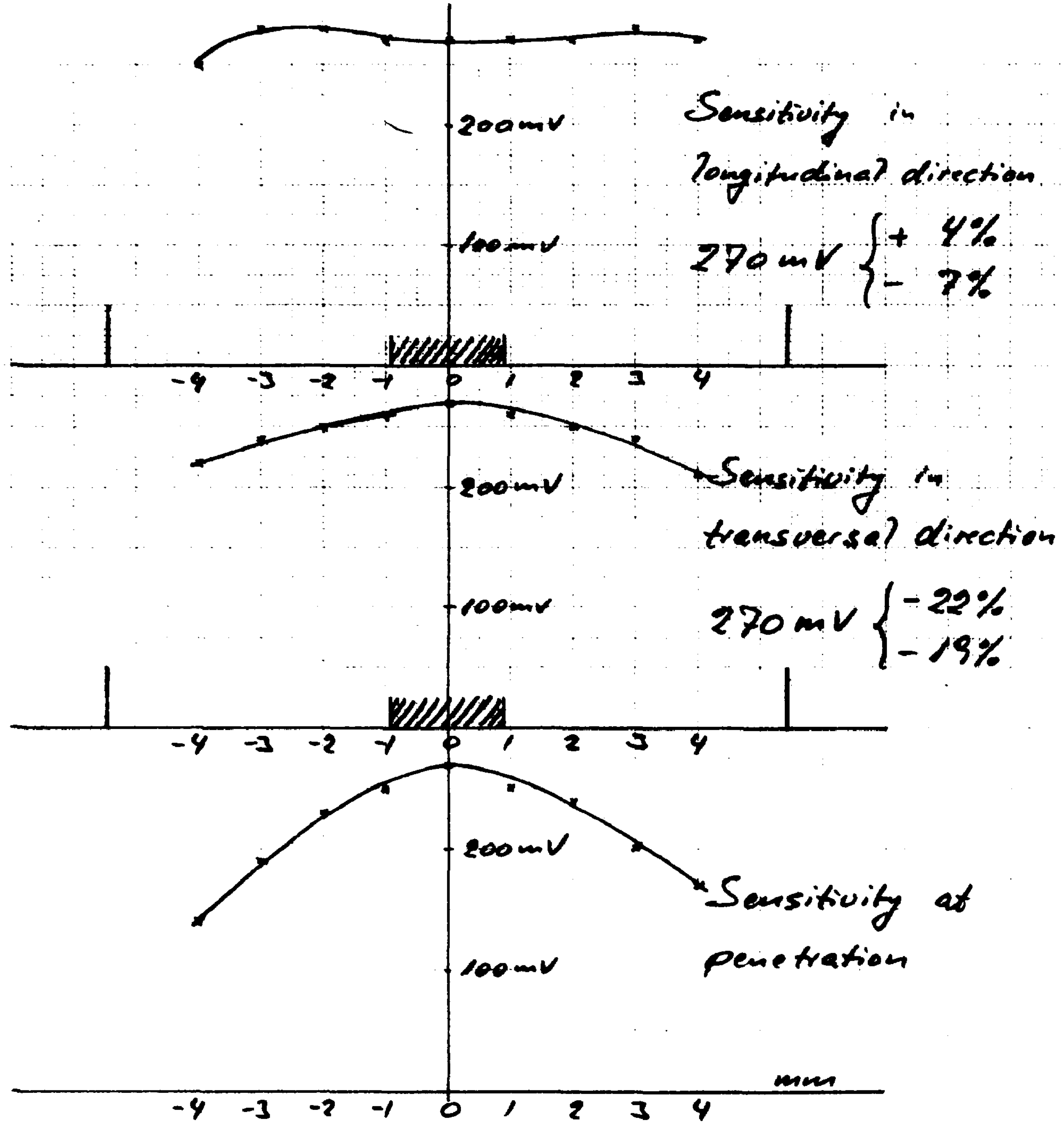


Cavity hole: 10.9 mm
Pellet size:
2.8 mm Teflon
corresponding to
4.0 mm deuterium

Without chimneypot

Average sensitivity for the
centre of mass of the pellet
inside a radius of 3 mm
905 mV ± 5.0%

Graph 6

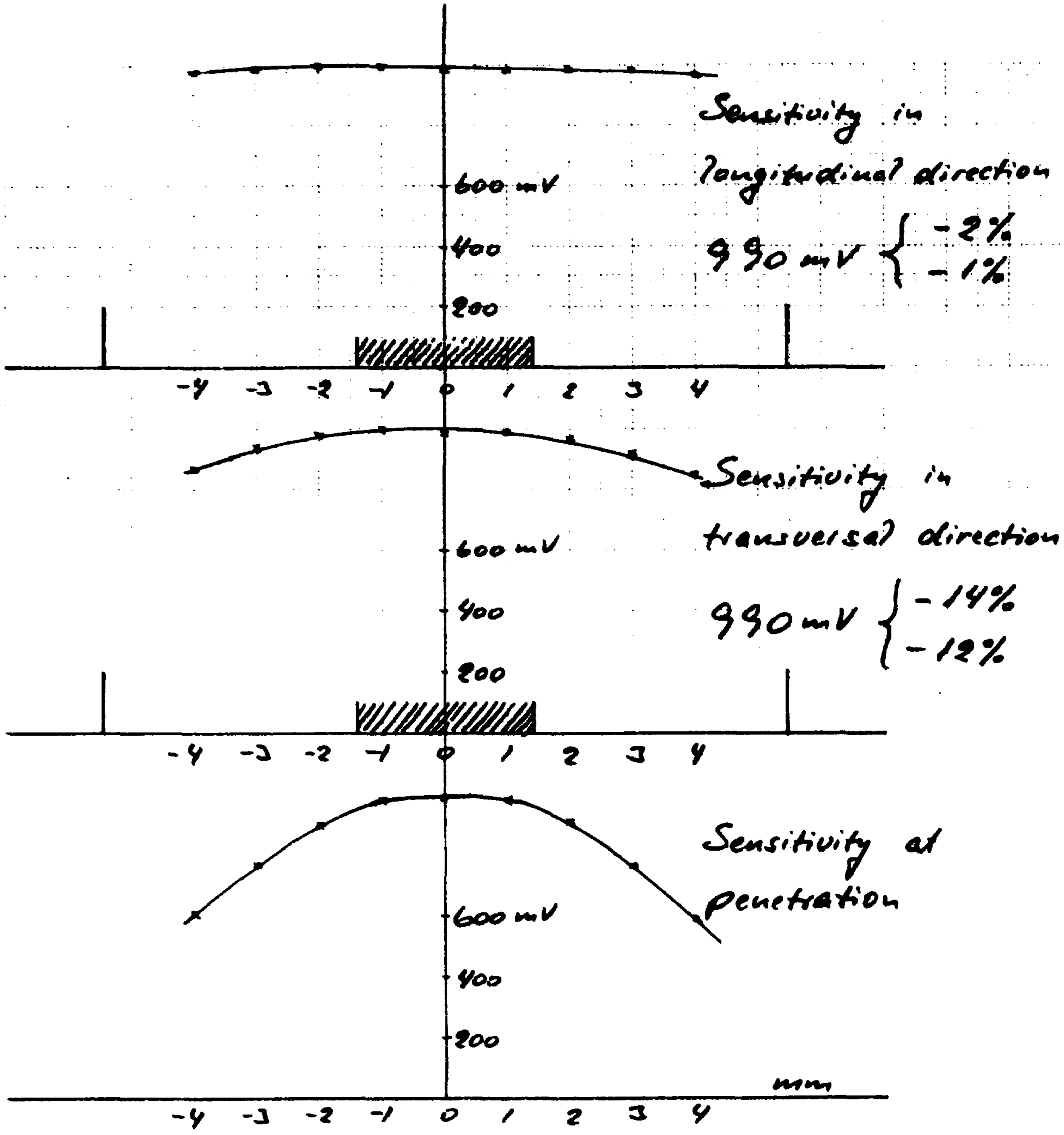


Cavity hole: 10.9 mm
Pellet size:
1.8 mm Teflon
corresponding to
2.6 mm deuterium

Without chimneypot

Average sensitivity for the
centre of mass of the pellet
inside a radius of 3 mm
260 mV ± 7.7%

Graph 7



Cavity hole: 10.9 mm

Pellet size:

9.8 mm Teflon

corresponding to

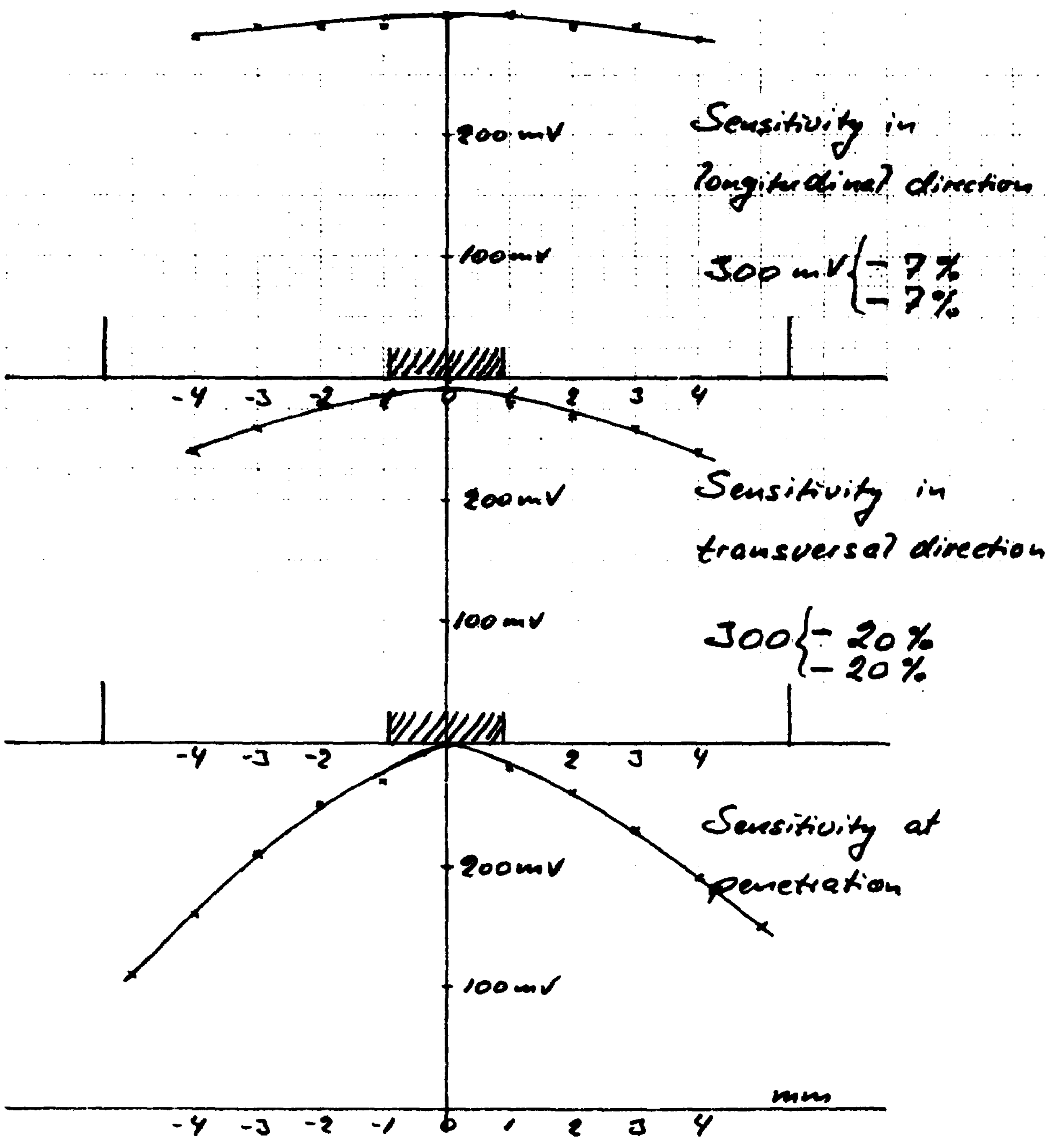
4.0 mm deuterium

With chimneypot

Average sensitivity for the centre of mass of the pellet inside a radius of 3 mm

955 mV ± 3.7 %

Graph 8

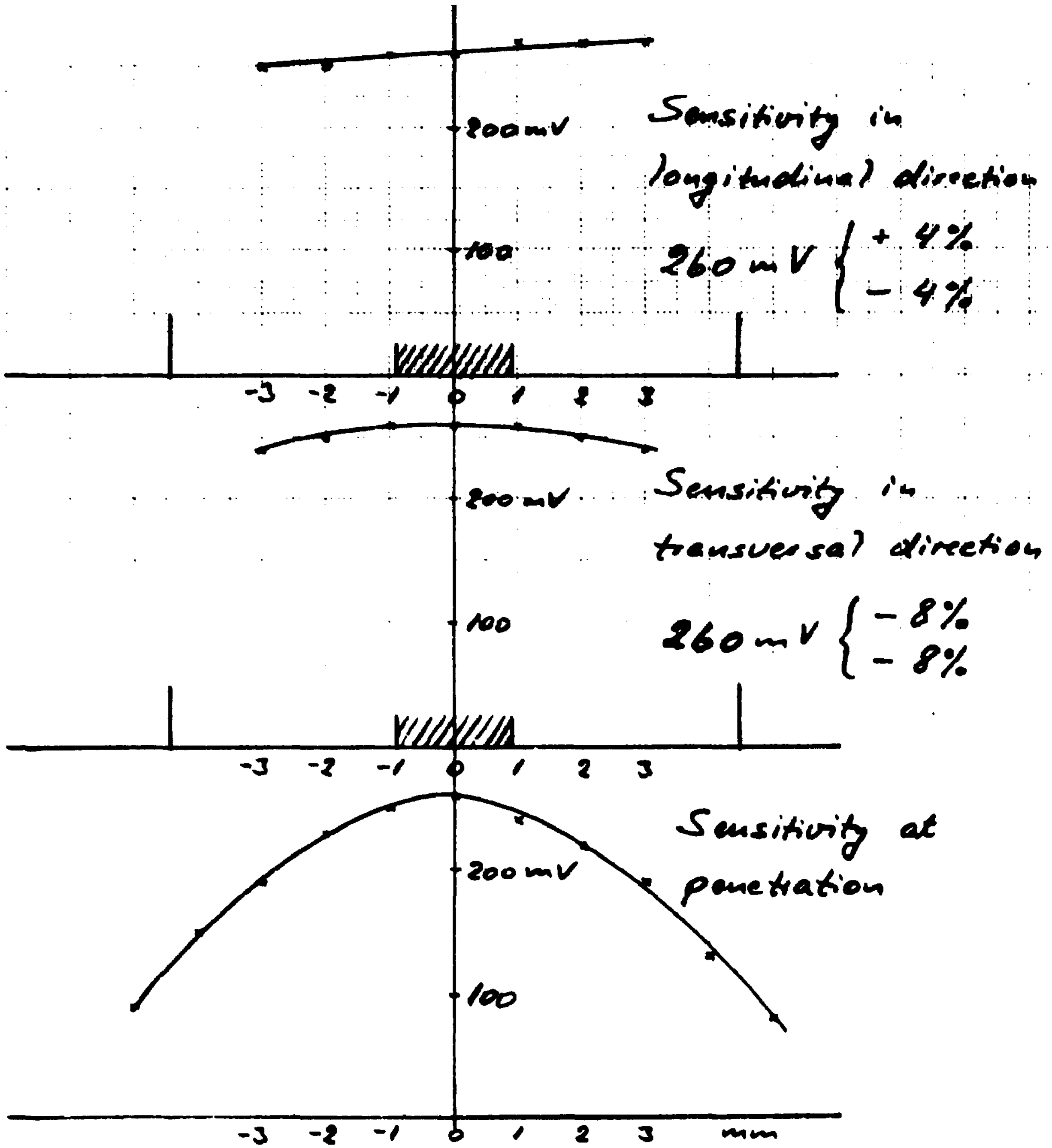


Cavity hole: 10.9 mm
Pellet size:
1.8 mm Teflon
corresponding to
2.6 mm deuterium

With chimneypot

Average sensitivity for the centre of mass of the pellet inside a radius of 3 mm
280 mV ± 7.1 %

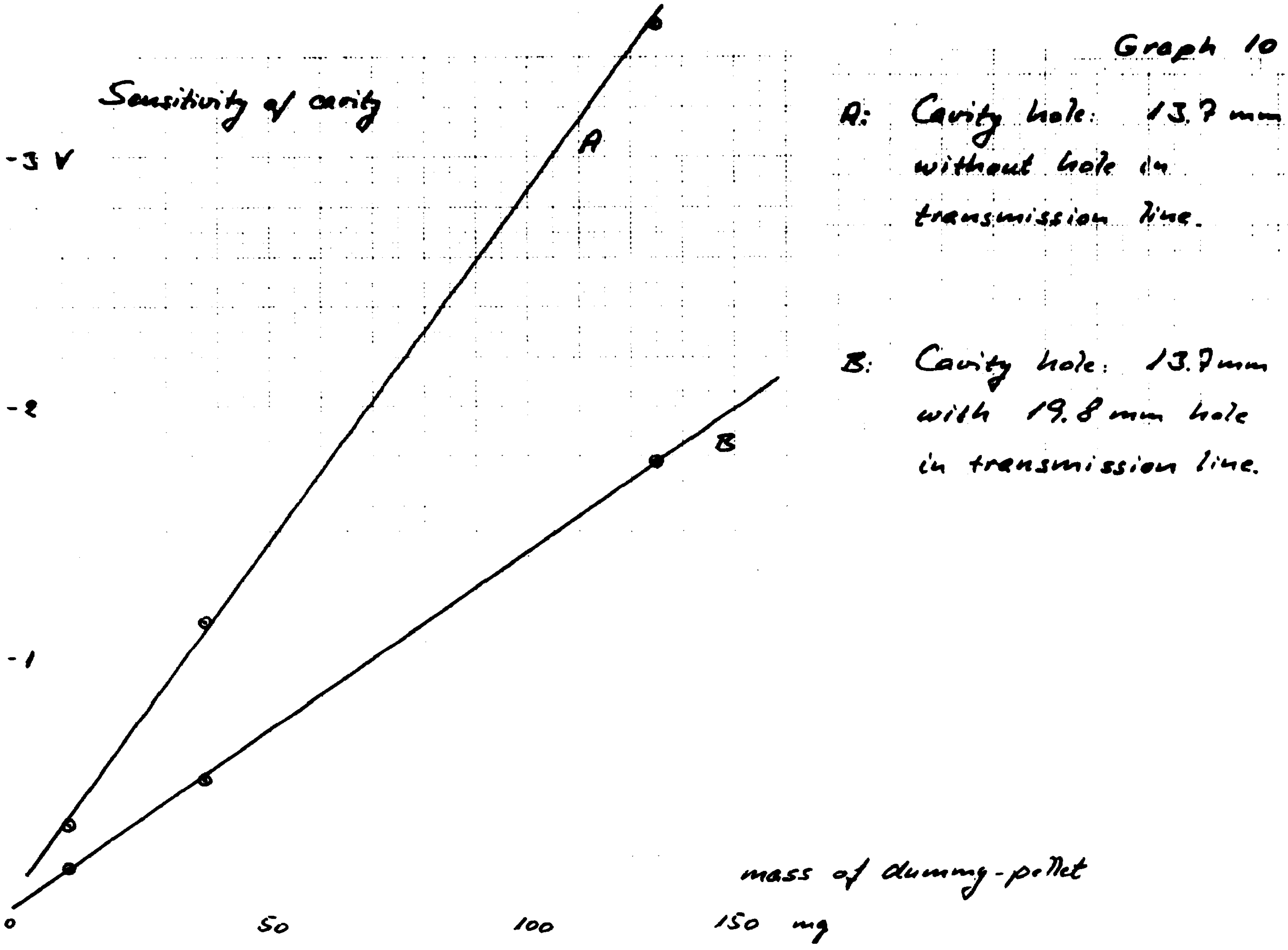
Graph 9



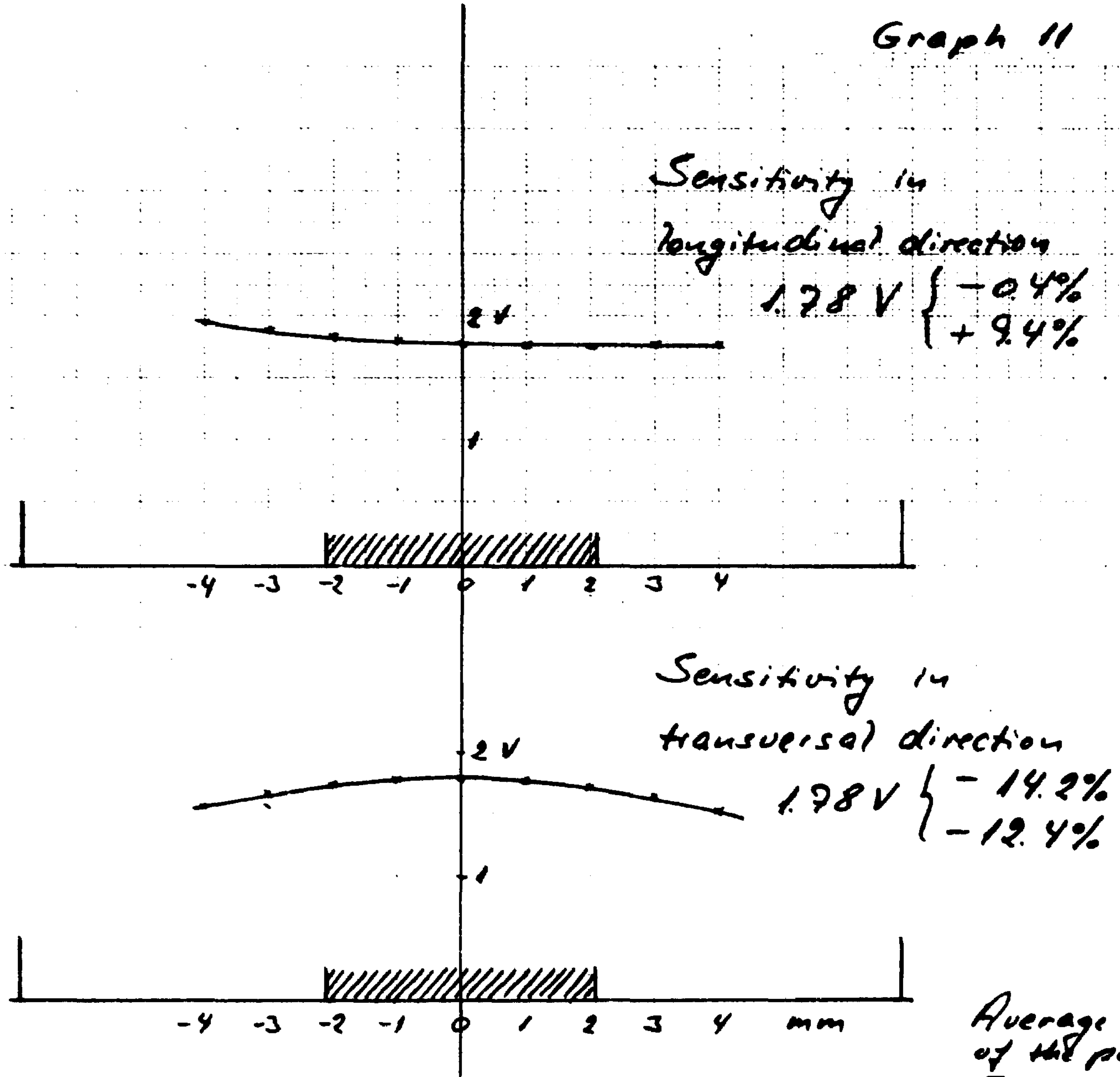
Cavity hole: 8.9 mm
without chimneypot

Pellet size:
1.8 mm Teflon
corresponding to
2.6 mm deuterium

Average sensitivity for the centre of mass of the pellet inside a radius of 3 mm
255 mV ± 5.9%


Graph 10
Sensitivity of cavity
-3 V
-2
-1
0
50
100
150 mg
mass of dummy-pellet
A
B
A: Cavity hole: 13.7 mm
without hole in
transmission line.
B: Cavity hole: 13.7 mm
with 19.8 mm hole
in transmission line.

Graph 11



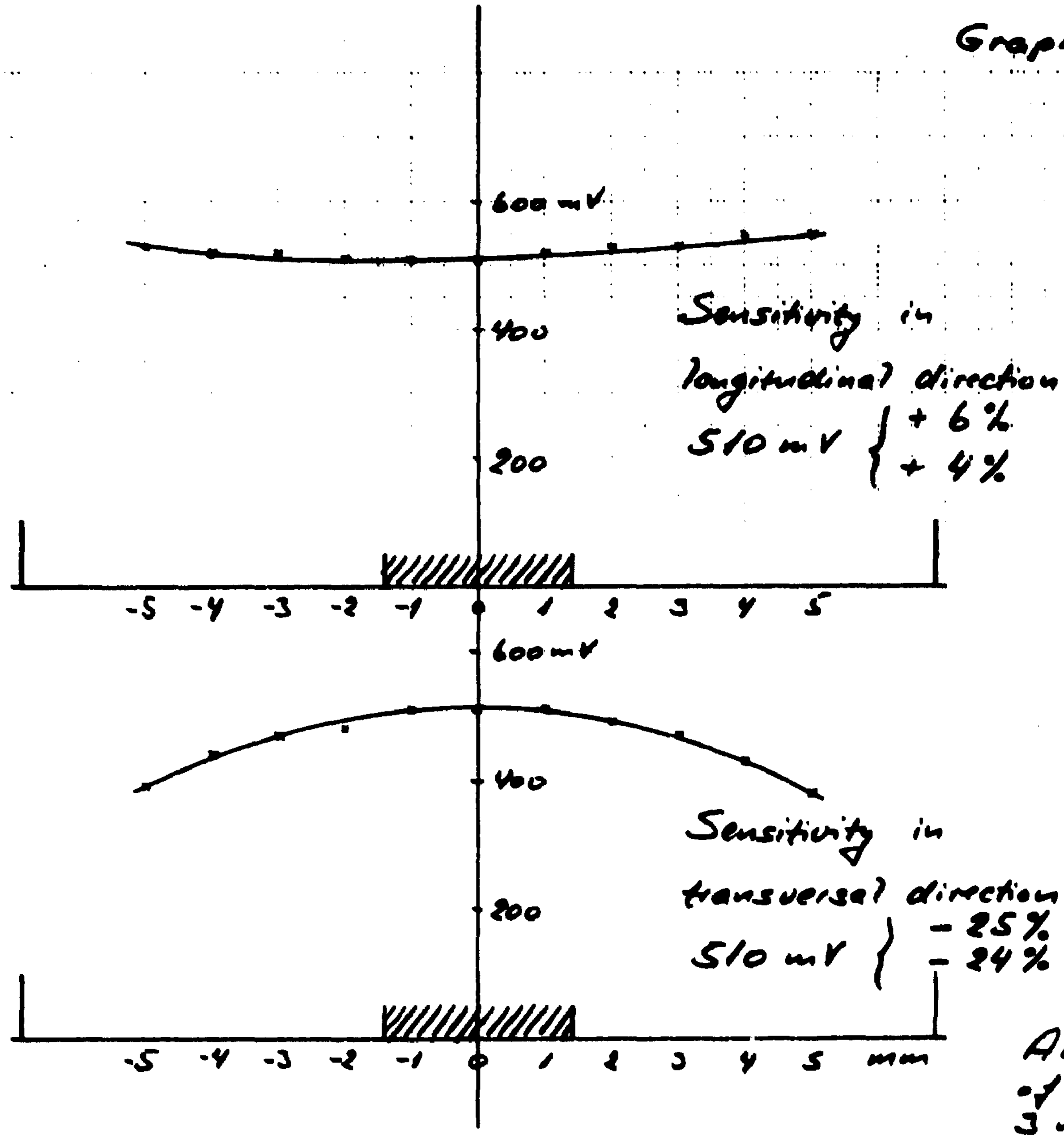
Cavity hole : 13.7 mm
With chimneypot

Hole in transmission line:
19.8 mm
With chimneypot
Pellet size :
4.2 mm Teflon
corresponding to
6.0 mm deuterium

Sensitivity in
Cavity hole

Average sensitivity for the centre of mass
of the pellet inside a radius of
3 mm : 1.77 V ± 6.8%
2 mm : 1.78 V ± 3.4%
1.5 mm : 1.78 V ± 2.2%

Graph 12



Cavity hole : 13.9 mm
with chimneypot

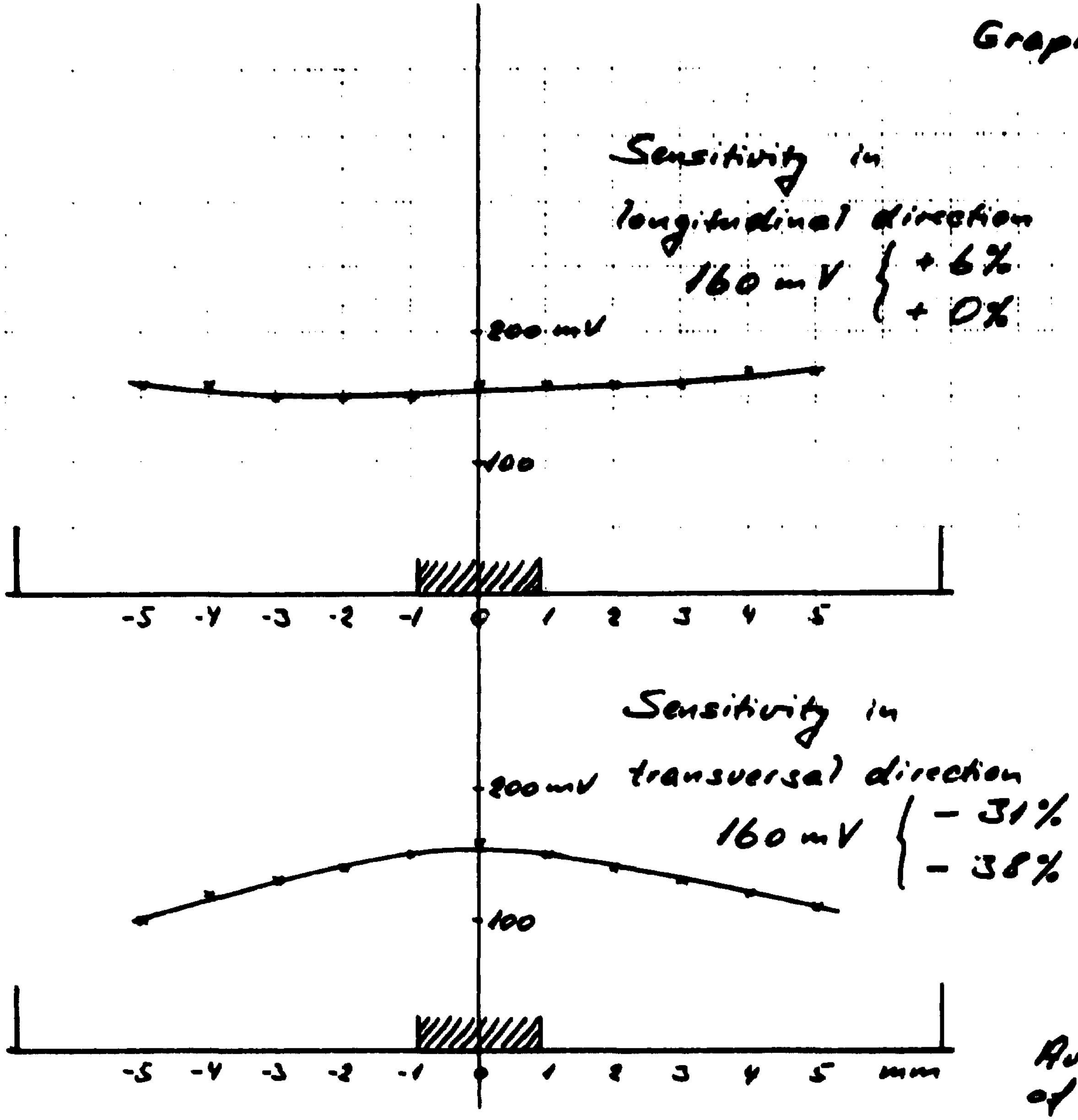
Hole in transmission line:
19.8 mm
with chimneypot

Pellet size:
2.8 mm Teflon
corresponding to
4.0 mm deuterium

Sensitivity in
Cavity hole

Average sensitivity for the center of mass
of the pellet inside a radius of
3 mm : 500 mV ± 6.0 %
2 mm : 510 mV ± 3.9 %
1.5 mm : 513 mV ± 2.4 %

Graph 13



Cavity hole: 13.7 mm
with chimneypot

Hole in transmission line:
19.8 mm
with chimneypot

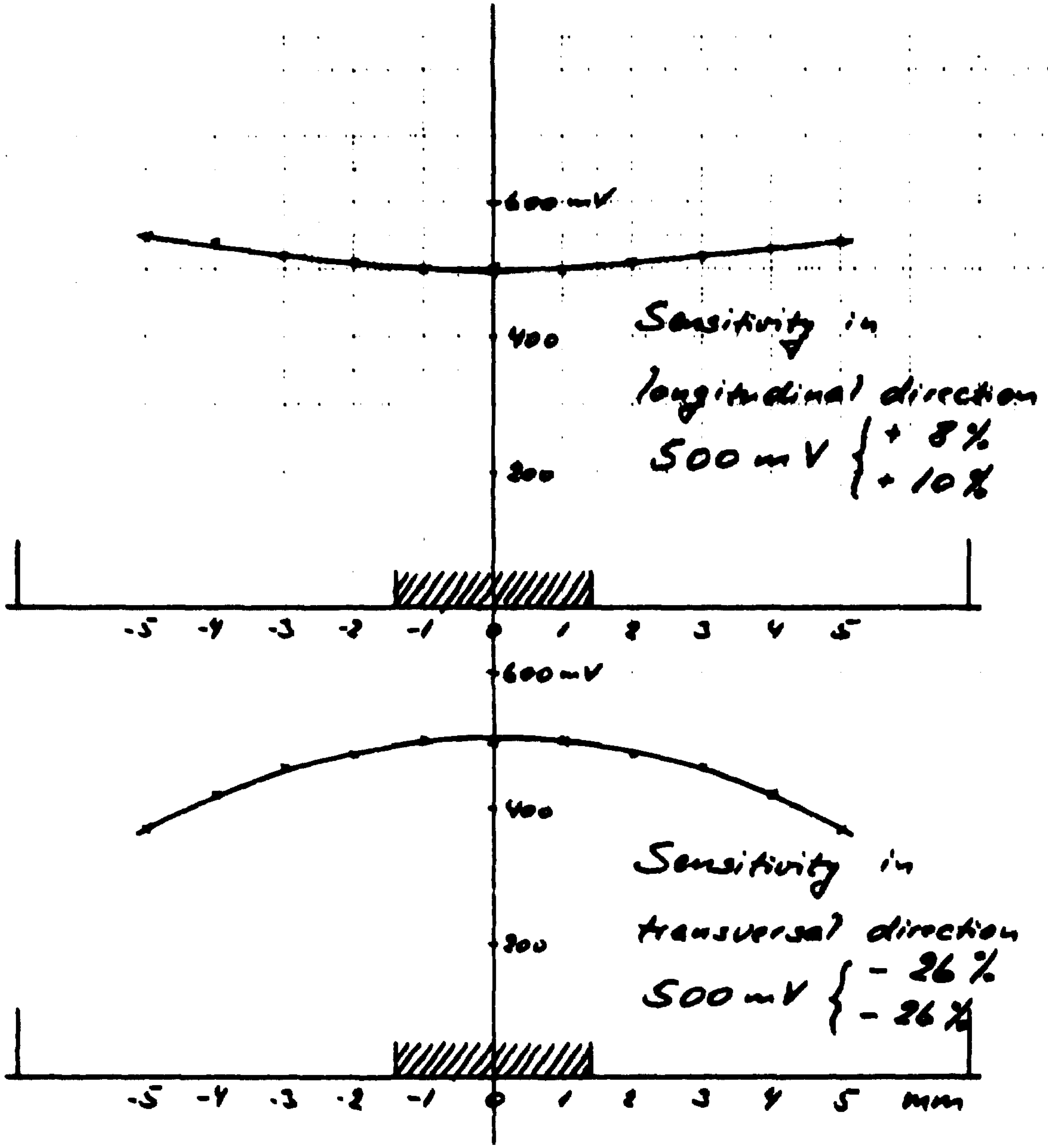
Pellet size:
1.8 mm Teflon
corresponding to
2.6 mm deuterium

Sensitivity in
cavity hole

Average sensitivity for the centre of mass of the pellet inside a radius of

3 mm: 145 mV ± 10.3%
2 mm: 150 mV ± 6.7%
1.5 mm: 153 mV ± 4.9%

Graph 14



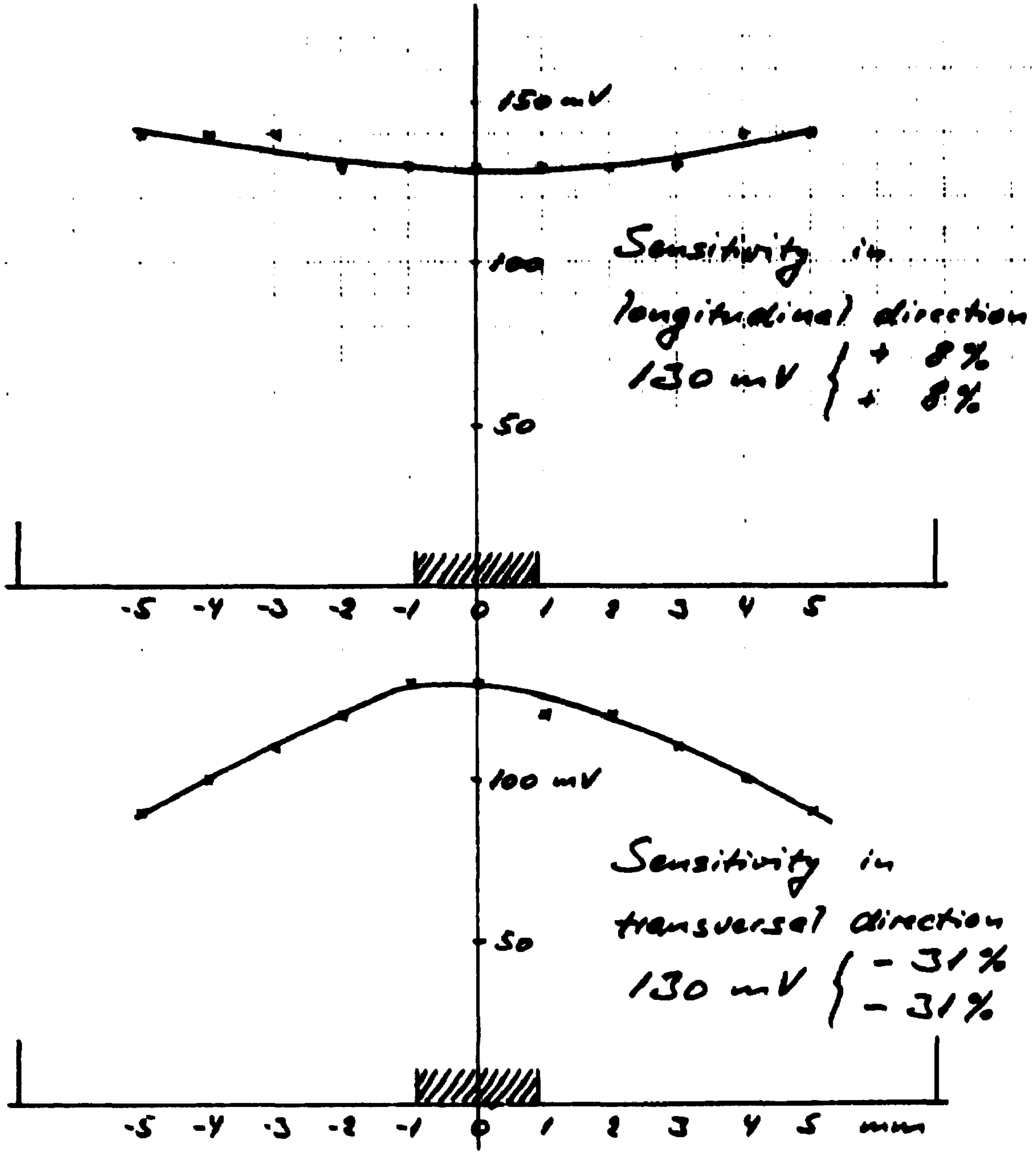
Cavity hole: 13.7 mm
with chimneypot

Hole in transmission line:
17.0 mm
with chimneypot

Pellet size:
2.8 mm Teflon
corresponding to
4.0 mm deuterium

Sensitivity in
cavity hole

Graph 15

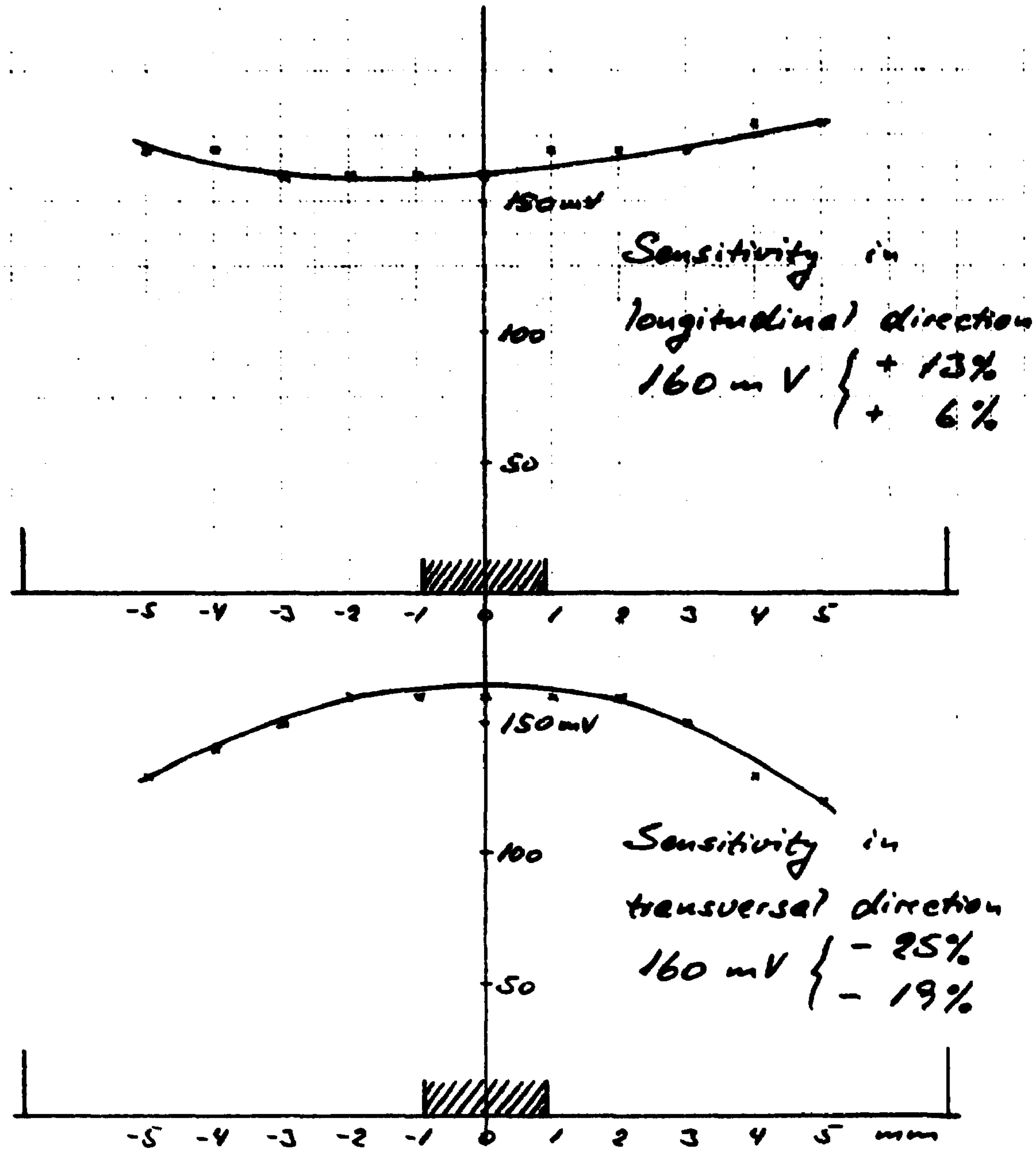


Cavity hole: 13.7 mm
with chimneypot

Hole in transmission line:
17.0 mm
with chimneypot

Pellet size:
1.6 mm Teflon
corresponding to
2.6 mm deuterium

Sensitivity in
cavity hole



Graph 16

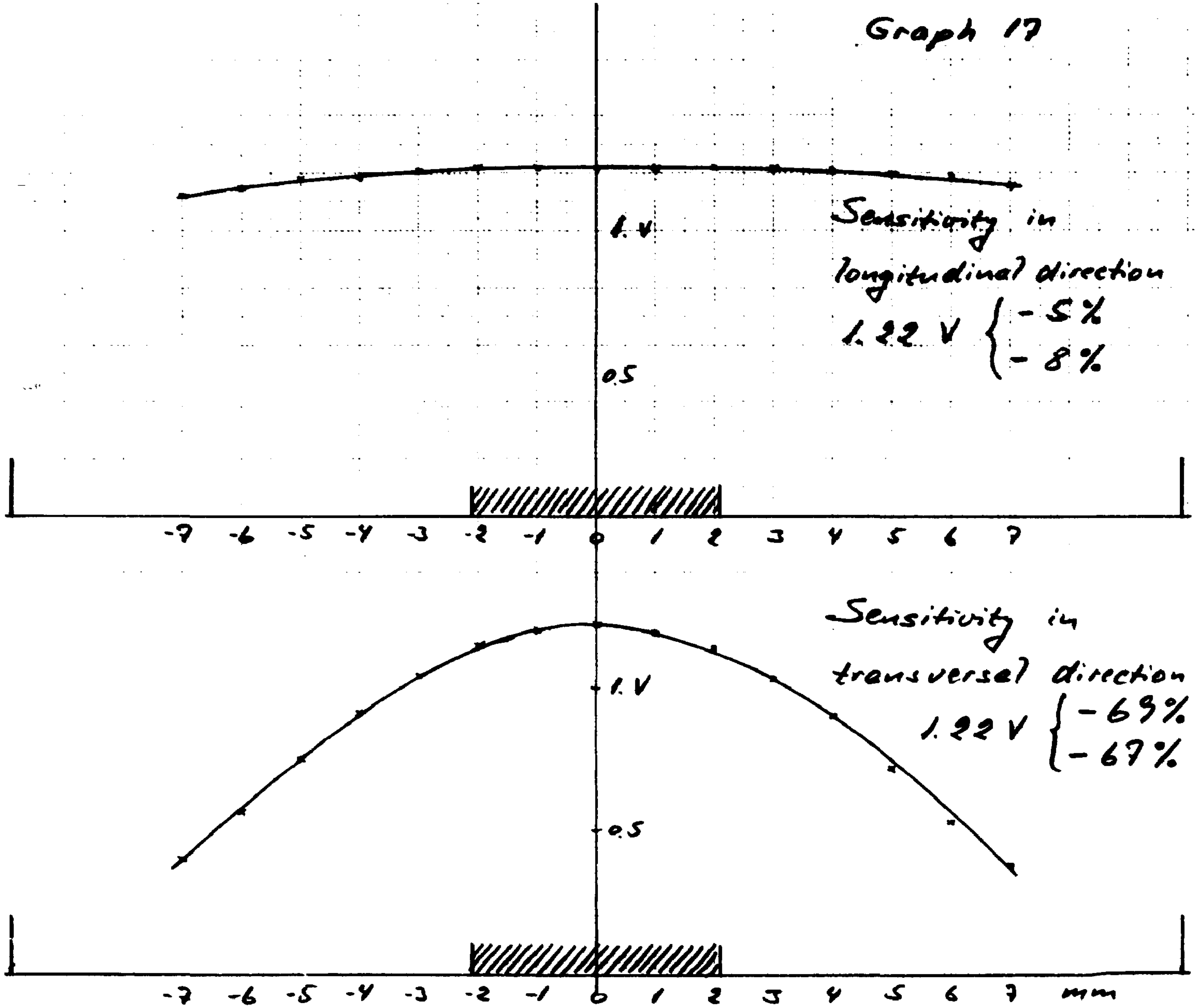
Cavity hole: 13.7 mm
with chimneypot

Hole in transmission line:
15.0 mm
with chimneypot

Pellet size:
1.8 mm Teflon
corresponding to
2.6 mm deuterium

Sensitivity in
cavity hole

Graph 17



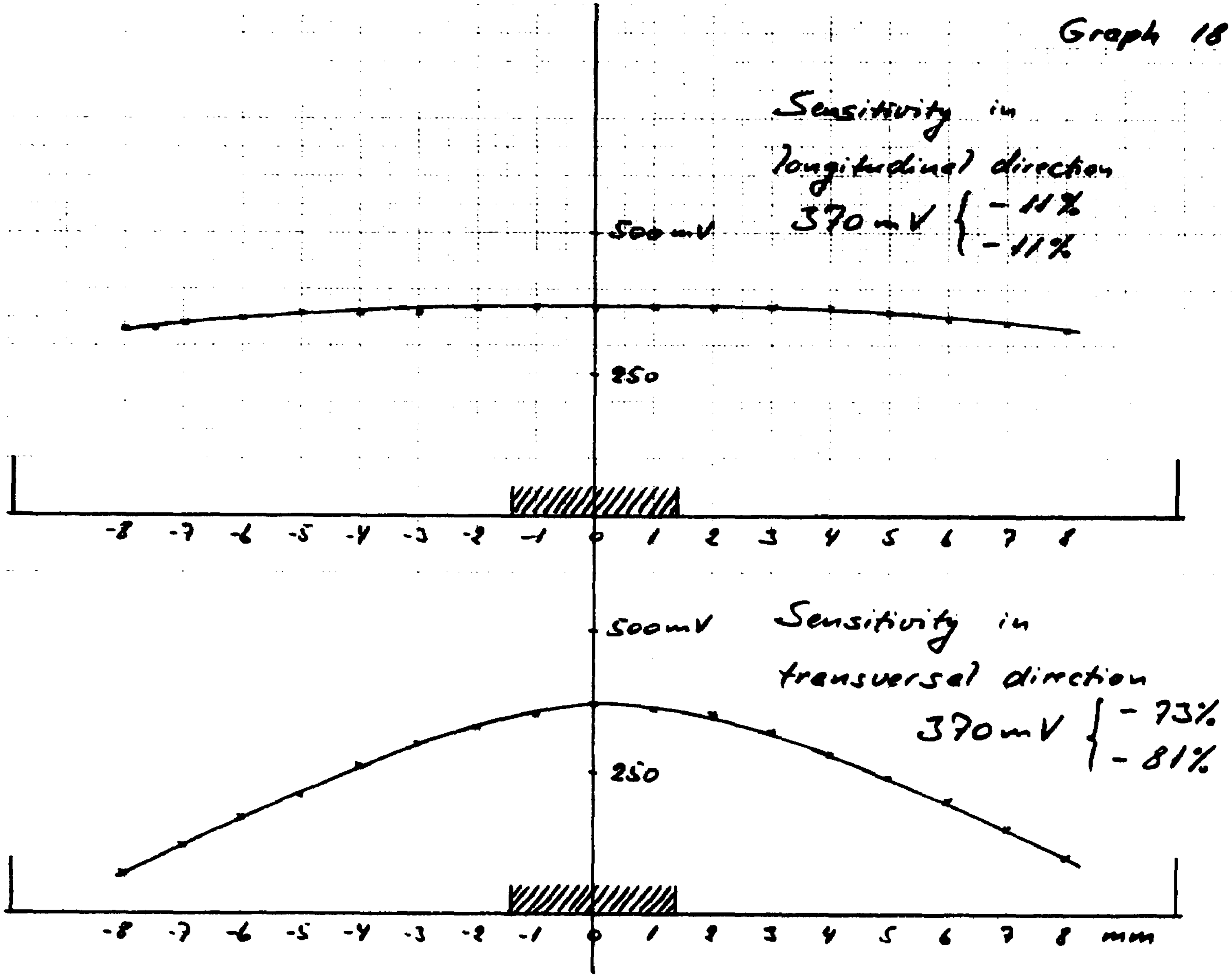
Cavity hole: 13.7 mm
With chimneypot

Hole in transmission line
19.8 mm
With chimneypot

Pellet size:
4.2 mm Teflon
corresponding to
6 mm deuterium

Sensitivity in
transmission-line hole

Graph 18



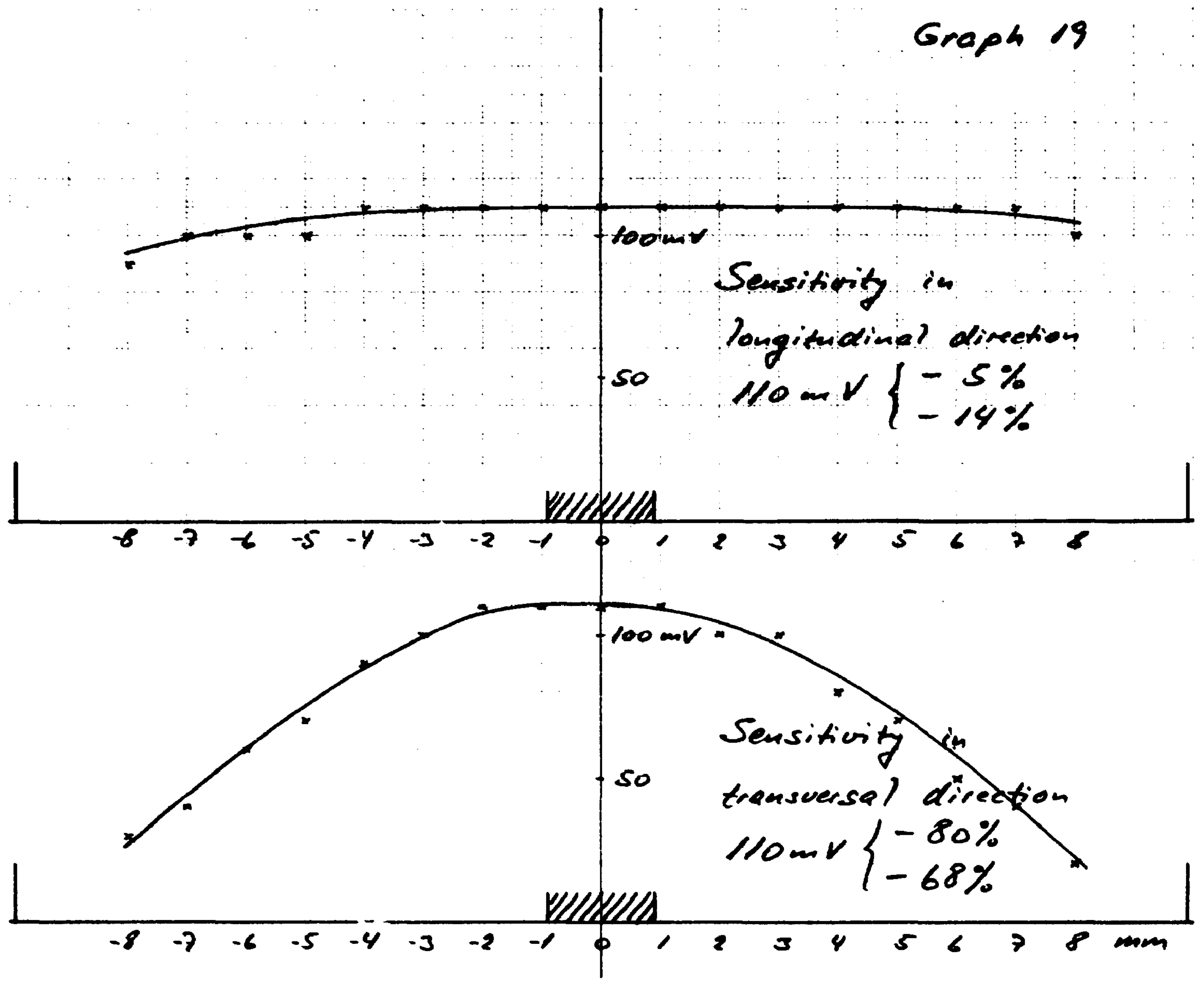
Cavity hole: 13.7 mm
with chimneypot

Hole in transmission line
19.8 mm
with chimneypot

Pellet size:
9.8 mm Teflon
corresponding to
4 mm deuterium

Sensitivity in
transmission-line hole

Graph 19



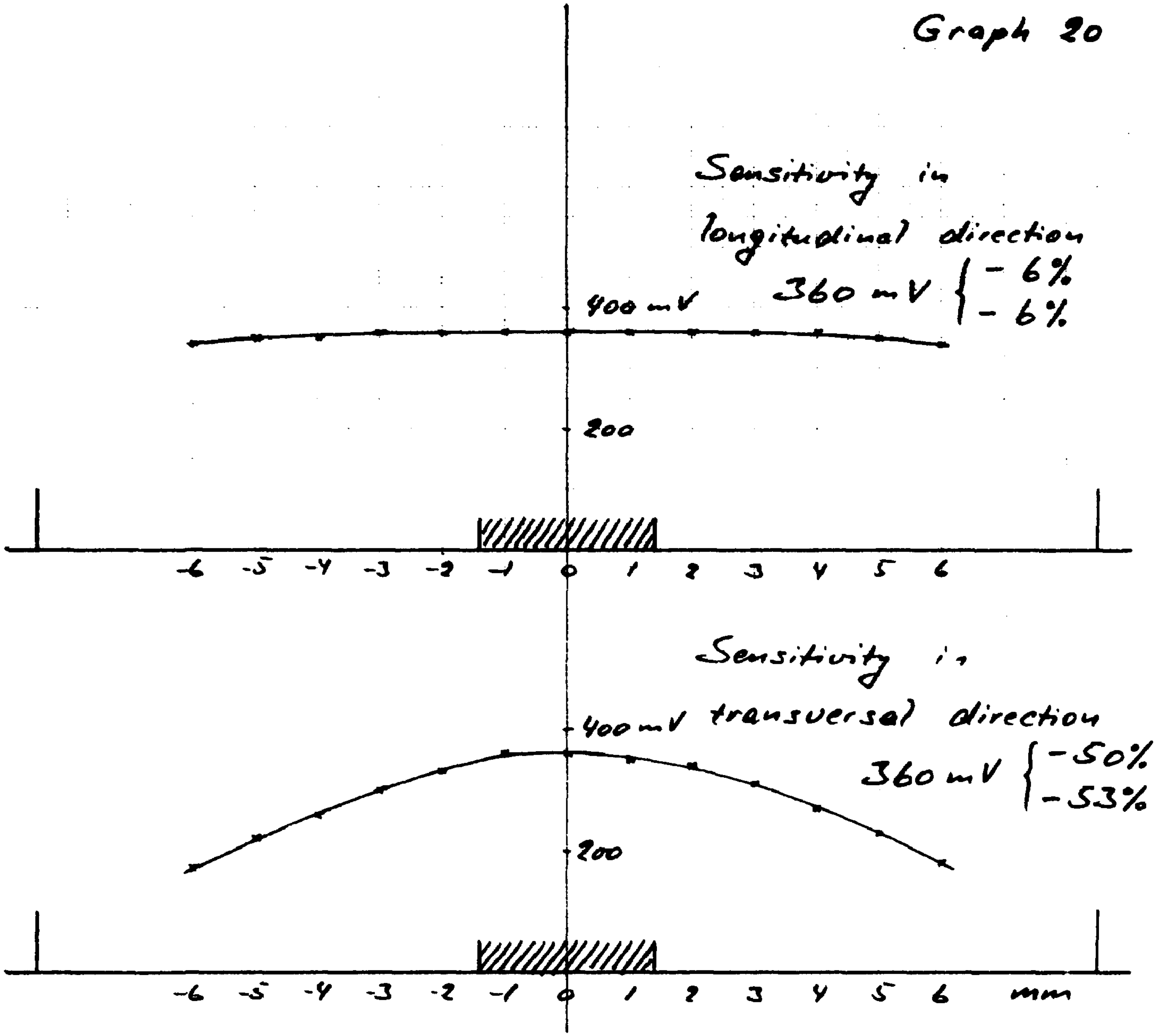
Cavity hole: 13.7 mm
with chimneypot

Hole in transmission line:
19.8 mm
with chimneypot

Pellet size:
1.8 mm Teflon
corresponding to
2.6 mm deuterium

Sensitivity in
transmission line hole

Graph 20



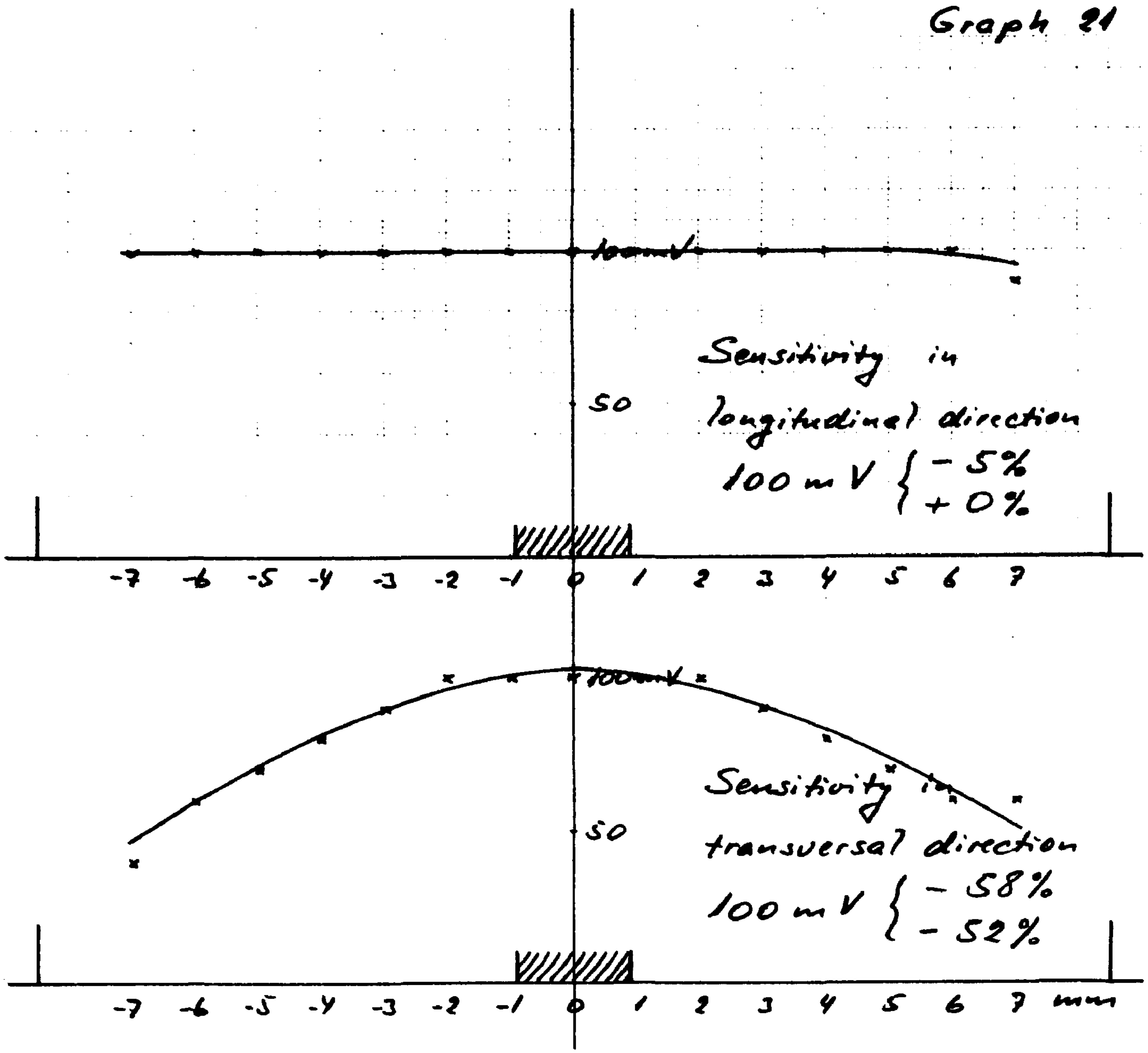
Cavity hole: 13.7 mm
with chimneypot

Hole in transmission line:
17.0 mm
with chimneypot

Pellet size:
9.8 mm Teflon
corresponding to
4.0 mm deuterium

Sensitivity in
transmission line hole

Graph 21



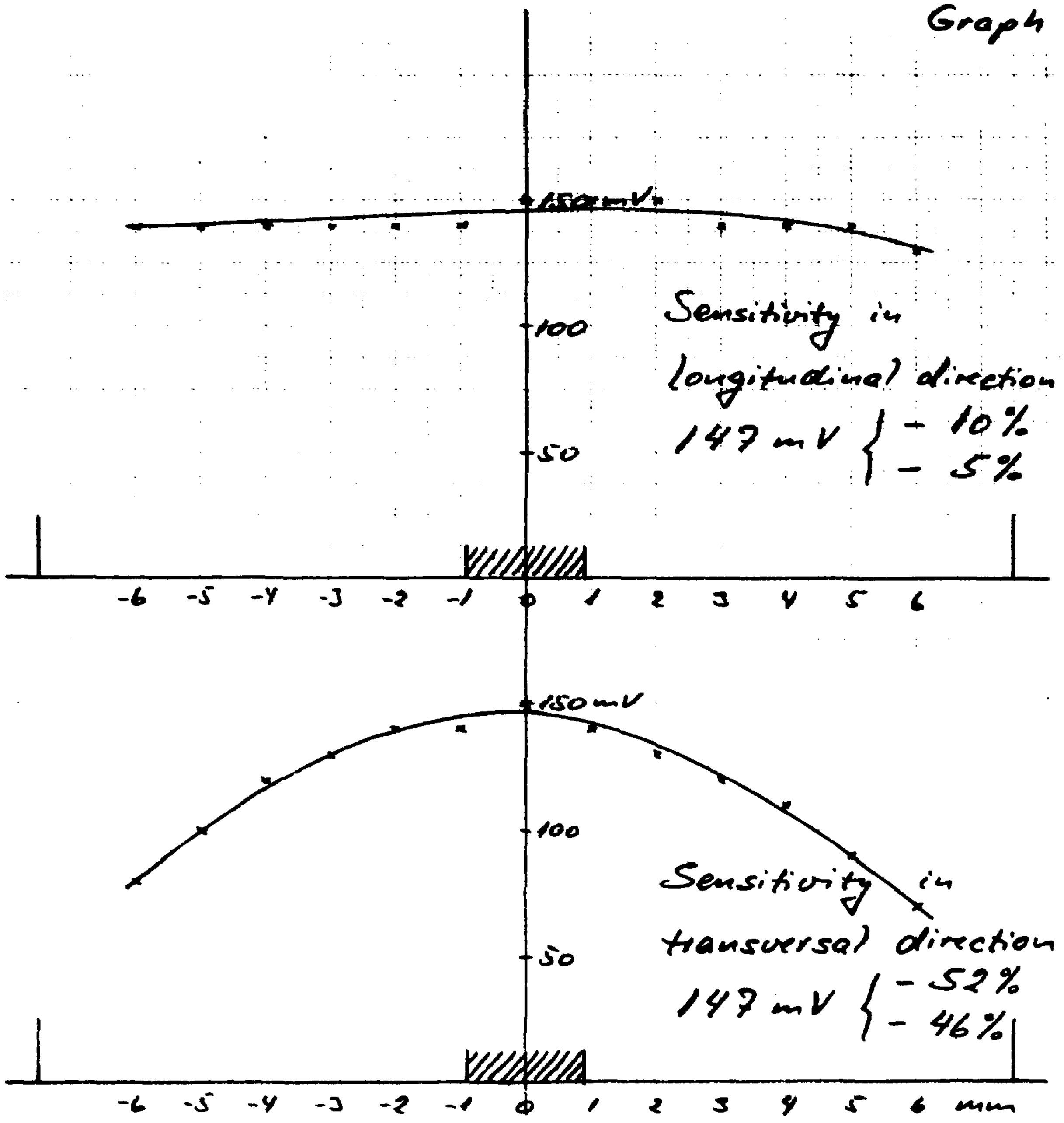
Cavity hole: 13.7 mm
with chimneypot

Hole in transmission line:
17.0 mm
with chimneypot

Pellet size:
1.8 mm Teflon
corresponding to
2.6 mm deuterium

Sensitivity in
transmission line hole

Graph 22



Cavity hole: 13.7 mm
with chimneypot

Hole in transmission line:
15.0 mm
with chimneypot

Pellet size:
1.8 mm Teflon
corresponding to
2.6 mm deuterium

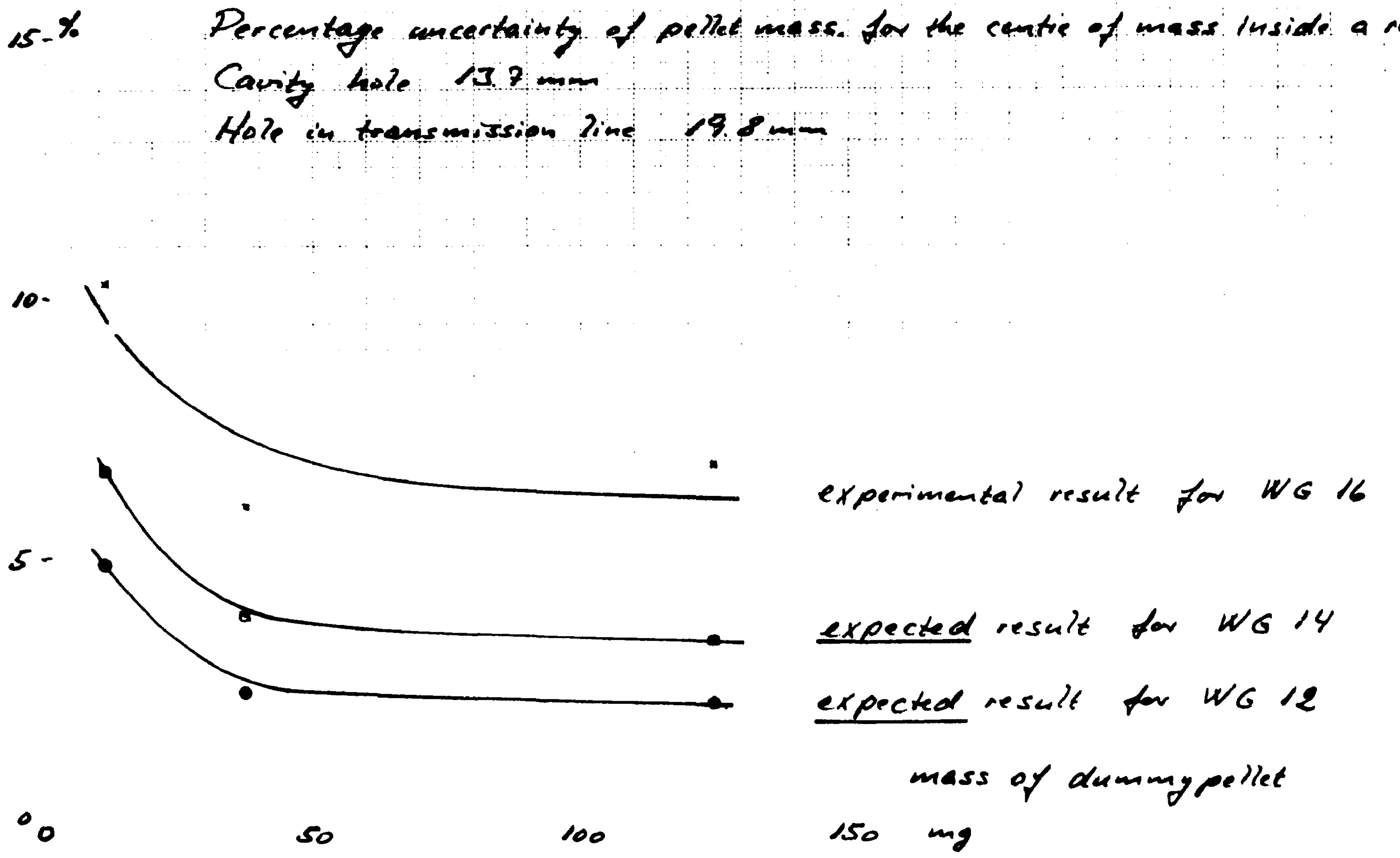
Sensitivity in
transmission line hole

Graph 23

Percentage uncertainty of pellet mass. for the centre of mass inside a radius of 3.0 mm

Cavity hole 13.7 mm

Hole in transmission line 19.8 mm



APPENDIX C

EXPECTED DECREASE IN SIGNALS AT LONG TRANSMISSION LINES

Attenuation in WG 16 at 9 GHz is about 13 dB/100m. This means that the waveguide will reduce the signal with a factor of two for every 23 m.

$$P = Po \exp(-x \ln 2/23) \qquad \text{(x is the length in meter)}$$

As the signal seen by the detector has travelled the waveguide twice, we have:

Waveguide length	Attenuation length	P/Po	Relative P/Po	Relative trans. length	Cavity signal	Trans. signal
0.9 m	1.8 m	0.95	1.00	1.00	1780 mV	1220 mV
7.0 m	14.0 m	0.66	0.69	7.77	1228 mV	108 mV
20.0 m	40.0 m	0.30	0.32	22.22	570 mV	18 mV

The cavity signal and transmission line signal at 0.9 m has been taken from the results in Graphs 11 and 17. From these signals the other cavity signals have been calculated from the extra attenuation (relative P/Po), and the other transmission line signals from the extra attenuation combined with the relative transmission length (relative trans. length). In the 7 m set-up we have measured about 1200 mV and 100 mV, respectively. However, in the new set-up another diaphram has been used between the transmission line and the cavity for optimal operation. This means that the shift in length is not the only difference between the two systems, and therefore the extreme fine agreement between the measured and the calculated results must be considered as a coincidence. Nevertheless, the calculation has been used to get an estimate of the expected signals for a 20 m long system, and it is seen that the cavity signal is expected to decrease with a factor of about 3, and the transmission line signal is expected to decrease with a factor of about 70 as compared to the 0.9 m set-up.

Risø National Laboratory **Risø - M - 2597**

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Abstract (Max. 2000 char.)

The feasibility of mass and velocity measurements on pellets in flight without use of optical equipment has been tested. The mass is measured by a microwave system, and the velocity is measured by a time of flight in a double interaction with the microwave system. The influence of the size of the pass-holes in the micro-wave guide tube has been discussed.

Descriptors

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